University of Alberta

Masking by Object Substitution: Interactions Between Visual Perception and Attention

by

Barry Lee Giesbrecht ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*

Department of Psychology

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Abstract

Understanding selective attention is at the core of psychological research (A. Allport, 1989). Constraints on selective attention were explored by investigating the interactions between attention and perception in the processing of rapid visual displays. Previous research has shown that if two targets are to be identified among distractors displayed in rapid sequence, correct identification of the first target hinders identification of the second. In the present thesis nine experiments are presented on this "attentional blink" (AB) phenomenon. Experiments 1-3 demonstrate that the AB requires masking of the second target by a temporally-trailing, spatially-superimposed pattern. It is proposed that during the AB a representation of the target is replaced by a representation of the mask (B. Giesbrecht & V. Di Lollo, 1998). This object substitution hypothesis has been incorporated into several models of the AB, however, it has not been tested. Experiments 4-8 test this hypothesis by masking the second target with an object substitution mask. If second target object substitution is crucial to the occurrence of the AB, then masking the second target by object substitution should produce the AB. This prediction was disconfirmed. Masking by object substitution was observed, but an AB was not observed. Experiment 9 was similar to Experiments 4-8 except that the second target mask had a distinct low-level component. This change produced a robust AB. The results force the rejection of the object substitution hypothesis and the modification of extant models of the AB. The results are explained by an alternative hypothesis that masking during the AB is mediated by mostly low-level visual processes. The constraints that these data place on selective attention are considered.

Dedication

I dedicate this thesis to my wife Cathy. Her love and support provide the foundation on which I am able to work and, more importantly, maintain balance.

I also dedicate this thesis to my parents, Albert and Vi, and in loving memory of Uncle Harry, Uncle Lawrence, and Grandma Walker.

Acknowledgments

I first want to thank my supervisors, Alan Kingstone and Walter Bischof. Together they have taught me two principles that will guide me in my future scientific endeavours: 1) do good science and 2) have fun while doing 1). Sincere thanks also to Vince Di Lollo, who has offered his wisdom throughout my graduate career. His comments and advice improved greatly the quality of this thesis.

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CHAPTER 1: INTRODUCTION

The ability of human observers to attend to one or few out of many possible stimuli involves complex neural selection mechanisms. Understanding these mechanisms is at the core of attentional research (Allport, 1989). Indeed, the consequences of invoking these mechanisms to selectively attend to events in the world have been well demonstrated in terms of behavioral and cortical responses. Behaviorally, advance knowledge of the form or location of a stimulus enhances the efficiency of processing the cued form or a stimulus presented in the cued location, relative to uncued forms or stimuli presented in uncued locations (e.g., Kingstone & Klein, 1991; Posner, 1980). Cortically, attention effects are manifested as changes in neural responses to stimuli that are attended as opposed to ignored (e.g., Mangun, Hillyard, & Luck, 1993; Moran & Desimone, 1985). Understanding the consequences of selective attention is an important key to understanding how selective attention supports coherent behavior. One approach to studying selective attention is to study the constraints imposed by perception on selective processing of visual information. With this issue in mind, the focus of this thesis is to investigate the fate of objects outside the current focus of attention. The aim is to provide insight into the neural mechanisms that underlie the interactions between selective attention and perception.

The structure of the opening chapter is as follows. First, I introduce the approach used to study the interactions between selective attention and perception. Second, I introduce the primary constraint with which the empirical results must be tempered. Finally, this chapter will close with a brief outline of the content of the thesis.

Tools for studying selective attention

Our visual world is in a continual state of flux, changing over time and space; our eyes are constantly moving and objects move from one location to another. Despite this constant change over time our perceptual experience is one of a constant stream of visual information, with no apparent gaps in awareness. Recent experimental work, however, has demonstrated that under certain conditions there are indeed gaps in awareness (Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; Rensink, O'Regan, & Clark, 1997). For example, when two objects are presented in rapid succession, attending to the first object interferes with attending to the second object for about 500 ms. This cost of attending to one object is revealed by the reduced likelihood of reporting (i.e., being aware) subsequent objects. Termed the attentional blink (AB, Raymond, et al., 1992), this cost of selective attention is thought to measure the temporal distribution of attention (Duncan, Ward, & Shapiro, 1994; Ward, Duncan, & Shapiro, 1996). What is tantamount for the present purpose is that during the AB, the second object is not attended. By manipulating variables that affect the unattended object one can address the question at the focus of this thesis: namely, what is the fate of objects that are outside the current focus of attention?

In all the experiments reported in this thesis, the key manipulations with respect to the second object are in the form of visual masking. Visual masking refers to the reduction in visibility of one stimulus, called the target, by another stimulus, called the mask, that is presented within close spatial and temporal proximity of the target (Breitmeyer, 1984). Research on visual masking has a long history dating back to the later part of the 19th century (e.g., Cattell, 1885) and has demonstrated that masking can be used to parse perceptual processes into different stages. In the present work, masking is used to isolate the processes that are disrupted by a mask when an object is not the current focus of attention. In other words, the AB and masking were used as tools to further the understanding of selective attention.

Neural basis of attention and perception

The primary goal of my research is to understand brain function and how it mediates behaviour. As stated at the outset, the functions of interest are those involved in selective visual attention. Given this broad goal, one is constrained by the functional and physical anatomy of the human brain. Consequently, understanding brain anatomy and function is essential for conducting sound research. In essence, the brain provides a constraint within which behavioural data must be interpreted.

In particular, the constraint within which my work is considered is the visual system. The visual system is a complex arrangement of interconnected neural networks. It is well established that there are two main visual pathways originating from the primary visual cortex (V1). The ventral pathway extends from V1 to the anterior infero-temporal cortex and is specialized for object perception, for determining "what" an object is. The dorsal pathway extends from V1 to the parietal cortex and is specialized for of spatial perception, for determining "where" an object is (Desimone & Ungerleider, 1989; Ungerleider & Mishkin, 1982)[1]. Both pathways are also connected to the prefrontal cortex: the ventral stream to Brodmann's areas 45 and 12; the dorsal stream to area 46. Connections between areas within each stream are both feed-forward and feed-back connections (Webster & Ungerleider, 1998). Several of the areas in each of the streams have been identified as playing critical roles in selective attention. For example, the posterior parietal lobe is thought to be critical for orienting attention in space (e.g., Posner & Petersen, 1990). More specifically, in monkeys the neural response to distracting objects has been shown to be suppressed in area V4 (Moran & Desimone, 1985); similarly, neurons in inferotemporal cortex of monkeys selective for an object have been shown to maintain an elevated rate of firing during a retention interval when that object is behaviourally relevant (Chelazzi, Miller, Duncan, & Desimone, 1993).

With this in mind, the results of the behavioural work presented in this thesis will be discussed as they relate to what is known about the structure and function of the visual system and the neural correlates of selective attention.

Thesis outline

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[1] Although I refer to the dorsal pathway as the "where" stream, there is substantial evidence that suggests that the dorsal stream is not solely for the processing of spatial location, but for processing of location for the purpose of guiding action (for a review see Milner & Goodale, 1995). In this way, the dorsal stream may more accurately be referred to as the "how" stream (Milner & Goodale, 1995). However, the intent here is merely to point out that there are two distinct processing streams that constrain models of visual processing.

The general approach taken throughout this thesis is to, by way of experimental manipulation, apply what is known about the AB and different forms of visual masking to further the understanding of the interactions between attention and perception. This section provides a brief outline of the subsequent eight chapters.

Chapter 2. This chapter represents the first work that systematically varied the form of masking with respect to the second target[2]. Two forms of pattern masking, simultaneous and delayed, are juxtaposed. It was found that the AB is observed only when the second target is masked with a delayed mask.

Chapter 3. The theoretical implications of the results presented in Chapter 2 are discussed in Chapter 3. More specifically, the results posed a problem for theoretical accounts of the AB. Emerging from this chapter is a hypothesis regarding the fate of unattended stimuli. This hypothesis accounts for the difference between simultaneous and delayed masking by suggesting that while attention is devoted to one object, the representation of a temporally-trailing object is labile and is susceptible to masking by a temporally-trailing, spatially-superimposed stimulus. The mechanism that is assumed to underlie the masking effect is one of object-substitution, whereby the representation of the mask replaces that of the unattended object in the visual system.

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[2] A version of Chapter 2 has been previously published as: Giesbrecht, B. & Di Lollo, V. (1998). Beyond the attentional blink: Visual masking by object substitution. Journal of Experimental Psychology, 24, 1454-1466. Copyright 1998 by the American Psychological Association (APA). Adapted by permission from the APA and the authors.

Chapter 4. The object-substitution hypothesis presented in Chapter 3 was based on related work on visual masking that demonstrated that a mere four dots that surround, but do not overlap, a target can act as a mask so long as the target and mask are presented in the same unattended location and the mask either temporally trails the target or when presented simultaneously, it has a longer duration than the target. This form of masking is known as masking by object substitution and is thought to be mediated primarily by high-level visual processes. Chapter 4 reviews the work that has used this type of masking and establishes a framework for the empirical work that is reported in Chapters 5-7. The experiments reported in these chapters apply a similar logic to that used in the experiments reported in Chapter 2. Again, the masking of the second target was manipulated. In these experiments, however, variables that are known to modulate the strength of four-dot masking are manipulated. The key manipulations were that of the distribution of attention over space and time. Distribution of attention over space was manipulated by spatial uncertainty and set size; distribution of attention over time was manipulated by the temporal separation between the first and second targets. The prediction was that if masking by object substitution disrupts the processing of an unattended object, modulating the strength of masking should modulate the severity of the AB correspondingly.

Chapter 5. Three experiments are reported in this chapter. In each of these experiments, the second target was always masked by an object substitution mask (i.e., 4-dots). In different blocks of these experiments, the second target and the mask were presented in the center of the screen or in one of four locations in the periphery. The purpose of presenting the target and mask in random locations was to observe masking by object substitution. As a first step, in Experiment 4 the 4-dot mask trails the second target, just as in the delayed mask conditions in Chapter 2. Although masking by object substitution was observed, there was no AB. The object substitution hypothesis was tested further in Experiments 5 and 6 by presenting the mask and the second target simultaneously and varying the duration of the four dots. In Experiment 5, the second target and mask were presented alone and an AB was observed in a single condition. However, in Experiment 6 when distractors were presented with the second target and mask (i.e., conditions more suitable for object substitution) no AB was observed.

Chapter 6. The two experiments reported in this chapter were very similar to the experiments reported in Chapter 5. However, in the experiments reported in Chapter 6 the conditions for object substitution masking were optimized. That is, the distribution of spatial attention was increased by increasing the spatial uncertainty of the second target display (Experiment 7) and increasing both the spatial uncertainty and set size. Masking by object substitution was observed in both experiments. However, despite the optimized conditions, no AB was observed.

Chapter 7. The failure to observe an AB in Experiments 4-7 could have been due to the change in paradigm, which involved switching spatial locations, or the change in the figural properties of the mask. To control for these possibilities the only experiment presented in Chapter 7 is a replication of Experiment 4, with a single difference: the 4-dot mask was changed to a digit mask. A robust AB was observed regardless of the location of the second target and mask. Thus, the lack of an AB in Experiments 4-8 was due to the mask.

Chapter 8. This chapter is a general discussion of the results of the empirical work presented in Chapters 5-7. The results are brought to bear on the object substitution hypothesis and other models of the AB. In contrast to the object substitution hypothesis, the results support the notion that primarily low-level processes are disrupted by masking an unattended visual object. In addition, the results are brought to bear on the purpose presented in Chapter 1: Understanding the neural mechanisms that underlie the interactions between selective attention and perception.

CHAPTER 2: VISUAL MASKING AND VISUAL ATTENTION

Visual attention can be deployed over space or over time. Deployment over space has been studied extensively with several different paradigms (see reviews by Kinchla, 1992, and by LaBerge, 1990). Deployment over time has been studied less extensively, mainly with two related paradigms. In one paradigm, known as rapid serial visual presentation (RSVP), stimuli are presented sequentially in the same location, and observers are asked to identify one or more targets within the stream. When two targets are to be reported, the first is identified almost perfectly, but identification of the second is substantially impaired. The impairment is most evident when the second target is presented with a temporal lag of about 200-500 ms after the first (Raymond, et al., 1992). At shorter or longer lags, performance is impaired less or not at all, thus yielding a characteristic U-shaped function over lags. This second-target deficit, also known as the attentional blink (AB), is said to occur because processing mechanisms required commonly by the two targets are unavailable (or are less available) for processing the second target until first-target processing has been completed (e.g., Chun & Potter, 1995). A very similar second-target deficit has been obtained in an elegantly simplified paradigm in which two targets, masked by trailing pattern-masks, are displayed at different screen locations, at various temporal lags from each other (Duncan, et al., 1994). The terms attentional blink and second-target deficit are used interchangeably in the present work.

Regardless of paradigm, a second-target deficit is obtained only if the target stimuli are masked. In the simplified paradigm (Duncan et al., 1994), masking is provided by temporally trailing patterns displayed in the same locations as the targets. In the RSVP paradigm, items are displayed sequentially in the same location at the rate of approximately one every 100 ms, so each target is masked by the ensuing item in the stream. The masking effect of the trailing item on the processing of the first target has been amply documented. For example, it has been found that if the RSVP item directly following the first target is omitted, thus introducing a 200-ms mask-free period, the second-target deficit is much reduced or eliminated (Chun & Potter, 1995; Raymond, et al., 1992; Seiffert & Di Lollo, 1997). The deficit is restored, however, if the first target and the mask are presented simultaneously and spatially superimposed on each other, even if that integrated display is followed by a 200-ms mask-free period (Seiffert & Di Lollo, 1997). Thus, whether the first target is masked by a simultaneous or by a temporally-trailing stimulus seems to be of little consequence to the second-target deficit.

Equivalence of simultaneous and delayed masks in respect to the second-target deficit is notable because the underlying masking processes are believed to differ substantially one from the other. The processing mechanisms subserving simultaneous and delayed masking are commonly referred to as integration and interruption, respectively (see reviews by Breitmeyer, 1984; Scheerer, 1973). The masking literature suggests that the two forms of masking act in very different ways and probably affect different phases of processing. In integration masking, the mask is said to degrade the target's earliest representation through a process equivalent to adding noise (the mask) to a signal (the target). Two characteristics of integration masking must be noted. First, masking is at a maximum when the target and the mask are presented simultaneously (i.e., when the stimulus-onset asynchrony, SOA, is equal to zero). Furthermore, the strength of masking diminishes symmetrically as the SOA is increased, whether the mask leads (forward masking) or trails (backward masking). Second, the strength of masking is not affected by the information content of the display, as indexed by the number of items in the target set (e.g., Spencer & Schuntich, 1970). In interruption masking, on the other hand, processing of the target is said to be disrupted by the arrival of the mask which takes over those processing mechanisms that are required in common for both stimuli. Interruption masking is found only when the mask is trailing (i.e., there is no forward masking), and masking is at a maximum not at simultaneity but when the mask follows the target after an optimal SOA. Moreover, masking increases with the information content of the display, as indexed by the number of items in the target set (e.g., Spencer and Schuntich, 1970).

A similar distinction has been drawn by Turvey (1973) who referred to the two forms of masking as peripheral and central, corresponding broadly to integration and interruption masking, respectively. Peripheral masking was said to occur at an early stage in visual processing and to respond to such factors as intensity, duration, and the relative energies of target and mask. Central masking, on the other hand, was said to occur at higher processing levels, and to be influenced by more cognitive factors. There is substantial evidence in the masking literature that integration (peripheral) masking is instantiated optimally by presenting the target and the mask simultaneously, spatially superimposed on each other, and that interruption (central) masking is instantiated optimally when the mask follows the target after a suitable SOA (Bachmann & Allik, 1976; Michaels & Turvey, 1973; Purcell & Stewart, 1970; Schiller, 1966; Spencer & Schuntich, 1970).

In the present work, we made use of the differences between the two forms of masking to study the second-target deficit. If it is the case that masking by integration and interruption are subserved by different mechanisms we reasoned that, by using the two forms of masking selectively, it may be possible to assess the relative roles of the salient mechanisms in the second-target deficit. For example, if the second-target deficit is obtained with masking procedure A but not with masking procedure B, then we can adopt the working hypothesis that the second-target deficit probably shares more mechanisms with the former than with the latter. At a first impression, however, this reasoning seems to be at odds with the available evidence. We have noted above that whether the first target is masked by integration (with a simultaneous mask) or by interruption (with a delayed mask) seems to make little difference to the second-target deficit. On this basis it could be concluded that the precise form of masking may not be an important consideration.

Such a conclusion, however, would be premature. At the very least, it would have limited generality, being based exclusively on results obtained with masking of the first target. To date, there have been no investigations of the second-target deficit in relation to the type of masking procedure used to mask the second target. To be sure, it is generally recognized by researchers in this area that in order to obtain a second-target deficit, it is necessary to mask the second target as well as the first. This is why in studies of the AB the second target is invariably followed by at least one distractor. However, the main reason for masking the second target has been to bring performance within a measurable range, thus avoiding ceiling effects (e.g., Moore, Egeth, Berglan, & Luck, 1996). In the present work, we show that the specific procedure employed to mask the second target has important consequences for the AB deficit. To wit, the deficit is obtained with interruption masking, but it is much reduced or entirely absent with integration masking. This differential effect provides novel constraints for theories of how sequential stimuli are processed in the visual system.

EXPERIMENT 1

In Experiment 1 we employed a conventional RSVP paradigm in which each item was displayed for 10 ms, and was followed by the next item after a blank interval of 90 ms. Within the RSVP stream, the two targets were upper-case alphabetical characters, and the distractors were digits of approximately the same size as the targets. The first target was always masked by the next item in the stream, as in conventional AB experiments (e.g., Shapiro, Raymond, & Arnell, 1994). In contrast, the second target was masked with either a simultaneous mask or a delayed mask.

In the simultaneous-masking condition, the second target was presented at the same time as, and spatially superimposed on, one distractor. Namely, the display consisted of the combined contours of the target-letter and one digit. embedded one within the other so as to form a single image, as illustrated in Figure 1. In this condition, the target was assumed to be masked by a process of integration. In order to avoid any possibility of masking by interruption, no trailing distractors were presented after the second target. Thus, in the simultaneous-masking condition, the RSVP stream ended with the presentation of the second target embedded with a digit. In the delayed-masking condition, on the other hand, the second target was presented alone, followed by a single distractor after a 90-ms interval. In this condition, the target was assumed to be masked chiefly by a process of interruption. Our intent was to juxtapose the two conditions in order to distinguish the effects of integration- and interruption-masking in the second-target deficit.

Two control conditions were employed. The first was a no-mask condition in which there were no trailing distractors after the second target. The effects of masking could thus be evaluated against a corresponding non-masked control. The second control was a condition with a variable number of trailing distractors presented after the second target. This provided a comparison with conventional AB experiments, in which the number of distractors presented after the second target varied inversely with the temporal lag between the two targets (e.g., Shapiro et al., 1994).

Method

Subjects

Twenty-four undergraduate students (9 male) from the University of Alberta subject pool participated for class credit. All had normal or corrected-to-normal vision based on self-report. None of the subjects participated in any of the other experiments reported here.

Apparatus and Stimuli

All the stimuli used in this and subsequent experiments were displayed on a Tektronix 608 oscilloscope equipped with P15 phosphor. The viewing distance was 57 cm, set by a headrest. All stimuli subtended approximately .8° of visual angle and had a luminance of 10 cd/m^2, as measured by a Minolta LS-100 luminance meter[3]. The distractor items were digits (0- 9), and the target items were letters from the English alphabet. The background and surrounding visual field were dark, except for dim illumination of the keyboard and response box.

Procedure

At the beginning of each trial a small fixation dot was presented in the centre of the screen, indicating where the RSVP items would be presented. Subjects initiated each trial by pressing a button on the response box. After a 500 ms delay, the RSVP stream was presented. Each item was displayed for 10 ms and was separated from the next item by an interstimulus interval (ISI) of 90 ms, yielding a presentation rate of 10 items/s. On any given trial, the distractors in the stream were selected randomly with replacement from the set of digits, with the constraint that the selected digit was not one of the two immediately-preceding items. The letter-targets were selected randomly without replacement from all letters of the English alphabet, excepting I, O, Q, and Z (these items were omitted due to their visual similarity to 0, 1, 7, and 2). The number of distractors preceding the first target was determined randomly on each trial and varied between 7 and 15. The second target was presented at one of seven lags after the first target. Subjects were required to identify the two letters in the stream and to enter them on the keyboard after the stream ended. Next, the fixation dot reappeared to indicate that the next trial was ready to begin.

---

[3] All luminance measurements reported in this thesis are based on measurements of a 1.5 cm x 1.5 cm patch of dots (44 dots x 44 dots). Consequently, due to luminance summation over space, the measurements are an overestimate of the actual luminance of the letters. Despite the overestimate, all letters were clearly visible.

Subjects participated in four blocks of trials in a single one-hour session. The four blocks differed with respect to how the second target was masked. In the No-mask condition, the RSVP stream ended with the second target. In the Stream-mask condition, the number of distractors following the second target was the same as in conventional AB studies. Namely, the first target was always followed by eight items, one of which was the second target, with the constraint that the second target was never the last item in the stream. In the Delayed-mask condition, the second target was followed by only one distractor, which was presented after the regular ISI (i.e., 90 ms). In the Simultaneous-mask condition, the RSVP stream ended with a display containing the second target overlaid by one distractor, so that the two stimuli formed a single configuration which was integrated both spatially and temporally. The display sequences in each of the four conditions are illustrated in Figure 1.

Insert Figure 1 about here

In each block, the temporal lag between the onsets of the first and the second targets varied between 100 and 700 ms, in steps of 100 ms. The second target was presented 12 times at each of the seven lags, resulting in four blocks of 84 trials. The order of presentation of the experimental blocks was counterbalanced across all subjects, so that each subject completed one of the 24 possible permutations of the four masking conditions. At the beginning of each session, subjects completed 14 practice trials in the Stream-mask condition. A brief rest period was introduced between blocks of trials.

Results

In this and all subsequent experiments, estimates of second-target identification were based only on those trials in which the first target had been identified correctly. This procedure is commonly adopted in AB experiments on the grounds that, on incorrect trials, the source of the error is unknown, so its effect on second-target processing cannot be estimated. Responses were recorded as correct regardless of the order of report. Mean percentages of correct identifications of the first target, collapsed across lags, were 88.6, 88.3, 86.9, and 86.3 for the Stream Mask, No Mask, Delayed Mask, and Simultaneous Mask conditions, respectively. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are presented in Figure 2. The results were analysed in a 4 x 7 repeated-measures analysis of variance (ANOVA) with two within-subjects factors: Masking Condition (Stream Mask, No Mask, Delayed Mask, and Simultaneous Mask) and Lag (100-700 ms). The analysis revealed significant effects of Masking Condition ($\underline{F}$ (3, 69) = 29.07, $\underline{p} < .001$, $\underline{MSE}$ = 797.34) and Lag ($\underline{F}$ (6, 138) = 18.77, $\underline{p} < .001$, $\underline{MSE}$ = 236.91). The interaction effect was also significant ($\underline{F}$ (18, 414) = 6.59, $\underline{p} < .001$, $\underline{MSE}$ = 149.63).

Insert Figure 2 about here

The comparison of major interest for the present purpose was between the Simultaneous Mask and the Delayed Mask conditions. Performance with the delayed mask (Figure 2A) revealed a pronounced second-target deficit whose temporal course was a U-shaped function commonly found in studies of the AB (Chun & Potter, 1995; Raymond et al., 1992; Seiffert & Di Lollo, 1997). Results with the simultaneous mask (Figure 2B) presented a fundamentally different picture: overall performance was impaired, but the temporal course of the impairment was substantially different from that obtained with the delayed mask. A separate ANOVA performed on the data for the Delayed Mask and the Simultaneous Mask conditions revealed a significant effect of Lag ($\underline{F}$ (6, 138) = 8.93, $\underline{p} <.001$, $\underline{MSE}$ = 237.70), but not of mask type ($\underline{F}$ (1, 23) < 1, $\underline{MSE}$ = 188.08). There was a significant interaction effect between Lag and Mask type ($\underline{F}$ (6, 138) = 6.71, $\underline{p} < .001$, $\underline{MSE}$ = 188.08), confirming that, although similar in overall mean level, the performance deficits obtained with the two forms of masking followed different time- courses. At its lowest point, performance in the Delayed-mask condition (Figure 2A, lag = 300 ms) was significantly lower than performance at the corresponding lag in the Simultaneous condition in Figure 2B (F (1, 138) = 8.71, $p < .004$, MSE = 188.08). Considered separately, performance with the simultaneous mask showed a modest but significant increment over lags (F (6, 138) = 2.83, $p <.02$, MSE = 184.47). In contrast, Lag had no significant effect in the No Mask condition (F (6, 23) = 2.11, $p >.05$, MSE = 53.91).

Discussion

The well-known AB deficit (Raymond et al., 1992) was replicated with a conventional RSVP paradigm in which the second target was masked by up to seven trailing distractors (Figure 2A). The results of the Delayed-mask condition showed that, just as in the simplified paradigm used by Duncan et al. (1994), multiple masks are not needed in the RSVP paradigm. That is, a single trailing item produced an AB deficit that was as strong as that produced by a stream of trailing items. What is more, if the trailing item was either omitted or integrated spatio-temporally with the second target, the AB deficit failed to appear. This was the key finding in Experiment 1, and deserves detailed examination.

At a strictly descriptive level, it can be said that performance on the second target was affected differently, depending on whether the mask was simultaneous or delayed. Beyond a descriptive level, it can be surmised that the pattern of results in Figure 2 may reflect a causal relationship between type of mask and second-target deficit. Specifically, it may be suggested that the deficit is mediated by processes that are triggered by delayed masks (i.e., interruption of processing), but not by simultaneous masks (i.e., stimulus degradation). Before this line of reasoning can be pursued with confidence, we must consider two aspects of the results that can create some ambiguity for interpretation: the fact that performance in the No-mask condition was near ceiling, and the finding of a significant improvement over lags in the Simultaneous-mask condition. These are discussed in turn, below.

We noted earlier that performance in the No-mask condition did not vary significantly across lags. On inspection, however, the No-mask curve in Figure 2B exhibits a clear, if muted, U-shape trend over lags, suggestive of a weak AB deficit. Since performance in this condition was near-perfect, we must consider the option that a second-target deficit failed to be revealed because performance was compressed against the 100% limit imposed by the response scale. On this option, an AB deficit might well have been revealed with a less constrained response measure. Although plausible, this option is inconsistent with the results of the Simultaneous-mask condition seen in Figure 2B. That is, performance with the simultaneous mask was well below ceiling, at a level where an AB deficit could have been measured, had it occurred. But the pronounced U-shaped deficit seen in Figure 2A failed to appear. Clearly, bringing performance within a measurable range cannot reveal an AB deficit unless the conditions for producing that deficit have also been met.

On a less plausible vein, it could be suggested that an AB deficit was latent in the No-mask condition and failed to appear when performance was brought within measurable range by using a simultaneous mask because the simultaneous mask itself might have prevented an AB deficit from appearing in some unspecified way. This option is dismissed in Experiment 2 in which an AB deficit was obtained under appropriate conditions even though the second target was degraded with a simultaneous mask. Rather, the pattern of results strongly suggests that the AB deficit hinges on the presence of at least one trailing item acting as a delayed mask on the second target.

Next, we consider the improvement in performance over lags in the Simultaneous-mask condition (Figure 2B). In the context of the AB, an improvement in performance over lags is thought to mirror the increasing availability of resources that can be deployed to the second target as processing of the first target nears completion. The results of Experiment 1 revealed a significant improvement over lags with both types of masks. With delayed masks (Figure 2A), the improvement occurred at the longer lags, after a rapid decrement during the first 300 ms. With simultaneous masks (Figure 2B), there was no initial decrement, and the improvement over lags was smaller, but it was statistically significant. The differences between the two performance curves are substantial, and justify the working hypothesis of different underlying mechanisms. By the same token, the possibility cannot be ignored that the improvement over lags in the Simultaneous-mask condition might represent a recovery from some form of initial second-target deficit. This possibility would cloud the distinction between the two forms of masking because it would indicate that an AB deficit may be obtained not only with delayed masks but also when the second target is degraded with a simultaneous mask. One possible reason for the improvement over lags in the Simultaneous-mask condition is examined in Experiment 2.

EXPERIMENT 2

In Experiment 1 we used two forms of masking with the intent of distinguishing between different processes underlying the second-target deficit. With simultaneous masks, we aimed at degrading the target's earliest representation by adding camouflage or noise. With delayed masks, our objective was to interfere with target identification through competition for higher-level mechanisms. A critical requirement in achieving these objectives was to avoid contamination between the two types of masking processes. For example, if the simultaneous mask acted not only to degrade the low-level representation of the target but also to interfere with its processing at a higher level, then the deficit in performance could not be ascribed unambiguously to either process.

It is possible that just such a contamination may have arisen in the Simultaneous-mask condition in Experiment 1. Because the mask consisted of a meaningful stimulus (a digit), the resulting interference with target identification could have arisen from at least two sources: degradation of the target by visual noise early in processing, and competition between two meaningful items (a letter and a digit) at a higher level of processing. From this perspective, the second-target deficit obtained with the simultaneous mask (Figure 2B) cannot be ascribed solely to degradation of the target's earliest representation, but must be ascribed, at least in part, to interference at a higher processing level. On this reasoning, the improvement over lags can be understood in terms of the cost inherent in processing multiple items at the same time, as suggested by Duncan (Duncan, 1980; Duncan, et al., 1994). To wit, on trials in which the second target was presented directly after the first target, three items (two letters and one digit) competed for the same high-level analysers, and performance suffered accordingly. At longer lags, more processing of the first target could be accomplished, thus freeing up resources for processing the second target, with consequent improvement in performance.

One way of resolving this ambiguity is to use a masking stimulus which, while degrading an low-level representation of the target, does not introduce another meaningful stimulus to compete with the target at a higher processing level. In Experiment 2 this was done by using a meaningless aggregate of random dots instead of a digit in the Simultaneous-mask condition.

A second objective of Experiment 2 was to evaluate the AB deficit obtained with simultaneous and delayed masks against corresponding control conditions in which the RSVP stream contained only one target. The single-target controls are needed because, at the most basic level, demonstration of an AB deficit requires a comparison between two conditions. In the experimental condition, the RSVP stream contains two targets; in the control condition, the first target is replaced by a distractor. Thus, the control stream contains only one target, whose location corresponds to that of the second target in the experimental stream. If performance on the second target is found to be lower in the experimental than in the control condition, the deficit can be ascribed to the effect of the first target.

Three masking procedures were explored in Experiment 2, each comprising an experimental and a control condition. The first was a replication of the Delayed-mask condition in Experiment 1, with the addition of the corresponding control condition. On the basis of earlier results (Raymond et al., 1992; Seiffert & Di Lollo, 1997), we anticipated large differences between control and experimental conditions, with near-perfect performance in the former, and a pronounced AB deficit in the latter. The second procedure was a replication of the Simultaneous-mask condition in Experiment 1, with a crucial modification: instead of a digit, the mask consisted of an aggregate of random dots overlaid on the second target. This ensured that masking occurred through degradation of the target's earliest representation, as distinct from interference between meaningful items at a higher processing level. We anticipated that such a mask should impair identification of the target both in the experimental and in the control conditions. More important, to the extent that simultaneous masking by noise does not mediate an AB deficit, we expected the level of performance to be the same in the two conditions. The third masking procedure consisted of a combination of simultaneous and delayed masks. In that condition, the second target was overlaid with random dots, as in the Simultaneous-mask condition, and was also masked by a digit displayed 90 ms later, as in the Delayed-mask condition. The objective was to rule out the option, discussed in Experiment 1, that the presence of a simultaneous mask might prevent the occurrence of an AB deficit in some unspecified way. We expected the simultaneous mask to reduce the level of performance equally across lags, and the delayed mask to produce an AB deficit. To the extent that the two effects combined additively, we expected to see an AB deficit at a lower overall level than that seen with a delayed mask alone.

Method

Procedures were the same as in the Experiment 1, with the following exceptions. Thirty undergraduate students viewed RSVP streams in six conditions, which were grouped in two sets. In one set the first target was present (Present set), in the other it was absent (Absent set). For ease of terminology, we refer to the only target in the Absent set as “second target” because the only target in the Absent set and the second target in the Present set were presented in corresponding positions within the RSVP streams. In both the Present and the Absent sets, the second target was masked in three different ways: By embedded dots, by a trailing item, and by both embedded dots and a trailing item. In the Simultaneous-mask conditions, the RSVP stream ended with the second target embedded in a patch of 100 dots that were positioned randomly on every trial within a notional square of 1° side. The number of dots used in the mask was determined by a pilot study in which we varied the number of dots in the mask, and the task was to identify the only target in an RSVP stream. We selected a 100-dot mask because it yielded a mean level of performance similar to that in the Simultaneous condition in Experiment 1. In the Delayed-mask conditions, the second target was followed by a single digit at an ISI of 90 ms. This was the same as the Delayed-mask condition in Experiment 1. In the Combined conditions, the second target was embedded in a patch of 100 dots (as in the Simultaneous condition) and was followed by a single digit at an ISI of 90 ms (as in the Delayed-mask condition). In all conditions, the second target was presented 10 times at each of the seven lags used in Experiment 1. The streams in the Absent set were the same as in the Present set, except that the first target was replaced by a digit. Thus, the lag between the two targets in the Absent set should be regarded as the lag of the second target relative to when the first target would have been presented, had it been included in the stream. The display sequences in each of the six conditions are illustrated in Figure 3.

Insert Figure 3 about here

Overall, this design resulted in two blocks of 210 trials, which were completed during a single one-hour session. Before each block, subjects completed 15 practice trials in the appropriate set for that block (Present or Absent) and a random assortment of the three masking conditions. Order of presentation of Present and Absent sets was counterbalanced across subjects.

Results

Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are presented in Figure 4. A problem arises when comparing Present and Absent conditions across lags. Because there was only one target in the Absent conditions, by definition there could be no lag between targets. For the sake of comparison with the Present condition, notional lags can be devised, based on the way in which the RSVP streams were constructed. To wit, the Present and Absent streams differed in a single detail: in the latter, the first target letter was replaced with a digit. Therefore, notional inter-target lags can be specified for the Absent conditions in terms of the temporal interval that elapsed from the presentation of the digit that replaced the first target and the presentation of the second target on any given trial. This has been done in Figure 4.

Insert Figure 4 about here

Mean percentages of correct identifications of the first target, collapsed across lags separately for each of the three Present conditions were as follows. Simultaneous mask: 87.4; Delayed mask: 88.0; Combined mask: 89.3. The results in Figure 4 were analysed in a 2 (first target Present or Absent (P/A)) x 3 (Mask: Simultaneous, Delayed, and Combined) x 7 (Lag: 100-700 ms) within-subject ANOVA. All main effects and interactions were significant, with the exception of one interaction effect of borderline significance; P/A: (*F* (1, 29) = 49.82, *p* <.001, *MSE* = 716.86), Mask: (*F* (2, 58) = 182.48, *p* <.001, *MSE* = 527.81), Lag: (*F* (6, 174) = 8.14, *p* <.001, *MSE* = 260.91), P/A x Mask: (*F* (2, 58) = 27.69, *p* <.001, *MSE* = 209.84), P/A x Lag: (*F* (6, 174) = 7.36, *p* <.001, *MSE* = 254.07), Mask x Lag: (*F* (12, 348) = 1.75, .05> *p* <.06, *MSE* = 716.86), P/A x Mask x Lag: (*F* (12, 348) = 3.29, *p* <.001, *MSE* = 193.30).

Separate ANOVAs were performed on the data in each panel of Figure 4. The objective was to carry out a direct comparison between Present and Absent conditions, separately for each masking procedure. The results were as follows.

For the results in Panel A (Delayed mask), all effects were significant; P/A: (F (1, 29) = 82.94, p <.001, MSE = 333.37), Lag: (F (6, 174) = 10.30, p <.001, MSE = 164.60), P/A x Lag: (F (6, 174) = 12.34, p <.001, MSE = 184.99). For the data in Panel B (Simultaneous mask) no effects were significant; P/A: (F (1, 29) = 1.48, p >.23, MSE = 344.01), Lag: (F (6, 174) = 1.18, p >.31, MSE = 198.04), P/A x Lag: (F (6, 174) = 1.00, p >.42, MSE = 180.16). For the data in Panel C, all effects were again significant; P/A: (F (1, 29) = 41.76, p <.001, MSE = 459.16), Lag: (F (6, 174) = 3.08, p <.007, MSE = 280.43), P/A x Lag: (F (6, 174) = 2.47, p <.03, MSE = 275.52).

Discussion

In Experiment 2 the second target was masked in three different ways. In each case, the effects of masking were examined by using two RSVP streams: an experimental stream which contained two targets, and a control stream which contained only one target whose temporal position in the display corresponded to that of the second target in the experimental stream. An AB deficit was said to have occurred if identification of the second target was poorer in the experimental than in the control stream. Based on this comparison, the deficit in identifying the second target could be ascribed to the requirement of having to process the first target. As an alternative control procedure, we could have used an RSVP stream containing two targets, with the subjects being asked to ignore the first one and to respond only to the second one. In this procedure, however, the first target would have been processed to an unknown extent, thus confounding the comparison with the experimental procedure. This confounding was obviated by using a single-target control condition.

Performance in the control conditions was highest with the delayed mask (Figure 4A), lower with the simultaneous mask (Figure 4B), and lowest with the combined mask (Figure 4C). In each case, performance remained at a steady level across lags. A vastly different pattern emerged in the experimental conditions. Pronounced AB deficits were obtained only in the two conditions in which the mask had a delayed component (Figures 4A and 4C). In both instances, the performance curves were similar to those obtained in other AB studies (Chun & Potter, 1995; Raymond et al., 1992; Seiffert & Di Lollo, 1997). Namely, performance was closest to the control levels at the shortest and longest lags, and showed the largest deterioration at lags of 200 and 300 ms. In contrast, no AB deficit was obtained with the simultaneous mask (Figure 4B): performance in the experimental condition did not differ significantly from that in the control condition either in overall level or in temporal course over lags.

This pattern of results confirms the key finding in Experiment 1: a pronounced AB deficit can be obtained with delayed-masking but not with simultaneous-masking of the second target. Further, the joint results of Experiment 1 and 2 indicate that simultaneous masking is ineffective in bringing about an AB deficit, whether the masking stimulus is a meaningful item, as in Experiment 1, or a meaningless set of random dots, as in Experiment 2. In this respect, it is interesting to note that the significant improvement over lags seen in the Simultaneous-mask condition in Experiment 1 (Figure 2B) was not found in the corresponding condition in Experiment 2 (Figure 4B; F (6, 174) = 1.35, p >.23, MSE = 202.30). Namely, the improvement occurred when the mask was meaningful but not when it was meaningless. This is what would be expected if the improvement over lags mirrored the cost inherent in processing multiple items at the same time, as was suggested in the Introduction of the present experiment.

One further point should be noted. The results in Figure 4C show that an AB deficit can be obtained even if the second target is degraded with a simultaneous mask, provided that it is followed by a delayed mask. On the evidence in the three panels of Figure 4, it looks as though simultaneous and delayed masks may combine in broadly additive fashion in their effects on performance. This supports the commonly-held view that the two forms of masking occur at different processing stages (e.g., Breitmeyer, 1984; Turvey, 1973). In addition, this finding is inconsistent with the option, noted in the Discussion of Experiment 1, that simultaneous masks may act to suppress the AB deficit.

EXPERIMENT 3

Simultaneous masking of the second target did not result in any AB deficits in Experiments 1 and 2, whether the mask was meaningful or meaningless. On the other hand, pronounced AB deficits were obtained in both experiments if the mask was delayed. In every case, however, the delayed mask consisted of a meaningful stimulus, namely a digit. This raises the question of whether the delayed mask needs to be meaningful, or whether an AB deficit can be obtained with a meaningless mask, provided that it is delayed. An answer to that question was sought in Experiment 3.

In Experiment 3, meaningless sets of random dots were used to mask the second target in RSVP streams. In any given stream, the mask was either embedded with the second target, as in the Simultaneous condition in Experiment 2, or it trailed the second target by a variable interval. Consistent with Experiment 2, no AB deficit was found when the target and the mask were displayed simultaneously. However, significant AB deficits were obtained when the mask was delayed.

Method

Procedures were the same as in the previous experiments, with the following exceptions. Thirty undergraduate students from the University of British Columbia viewed RSVP streams in four conditions. The conditions differed in respect to the SOA between the second target and a dot-mask. The SOAs between the second target and the mask were 0, 50, 100, and 200 ms. The mask was the same as in the Simultaneous-mask condition of Experiment 2: it consisted of a patch of 100 dots positioned randomly on every trial within a notional square of 1° side. Thus, the 0-SOA condition in this experiment was exactly the same as in the Simultaneous-mask experimental condition of Experiment 2. Similarly, the 100-ms SOA condition was the same as the Delayed-mask experimental condition in Experiment 2, except that the mask consisted of a meaningless group of dots instead of a digit. In all conditions, the second target was presented 15 times at each of the seven lags used in the previous experiments. The order of presentation of the different conditions was randomized.

Overall, this design resulted in 420 trials, which were completed during a single one-hour session. At the beginning of the session, subjects completed a block of 15 practice trials that consisted of a random assortment of the different conditions. Within the testing block, theorder of presentation of the different conditions was randomized for each subject. The experimental trials were separated into four blocks, and participants were offered a break between blocks.

Results and Discussion

Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are presented in Figure 5, separately for each SOA. Mean percentages of correct identifications of the first target, collapsed across lags, were: 90.3, 89.4, 87.6, and 87.3 ms for SOAs of 0, 50, 100, and 200 ms, respectively. The results in Figure 5 were analysed in a 4 (SOAs) x 7 (Lags) within-subject ANOVA. All effects were significant. SOA: (*F* (3, 87) = 58.41, *p* <.001, *MSE* = 349.69), Lag: (*F* (6, 174) = 9.10, *p* <.001, *MSE* = 122.39), SOA x Lag: (*F* (18, 522) = 1.76, *p* <.03, *MSE* = 88.93).

Insert Figure 5 about here

No AB deficit was found when the target and the mask were displayed simultaneously (Figure 5, SOA = 0). A separate ANOVA showed the effect of Lag in the zero-SOA condition to be non-significant (*F* (6, 174) < 1). This parallels the results obtained with the simultaneous mask in Experiment 2. On the other hand, significant AB deficits were obtained at all other SOAs, including 200 ms (*F* (6, 174) = 3.18, *p* <.01, *MSE* = 48.07). Notably, a separate ANOVA carried out on the data for the zero-SOA and 50-ms-SOA conditions revealed a significant interaction effect between SOA and Lag: (*F* (6, 174) = 2.78, *p* <.01, *MSE* = 132.10). This shows that the introduction of a 50-ms SOA is sufficient to bring about an AB deficit.

On the basis of these results, it can be concluded that, in order to bring about an AB deficit, a delayed mask must be presented after the second target; but the mask itself need not be a meaningful stimulus. This said, it must be noted that although meaningful masks are not necessary, they do yield larger AB deficits. This is revealed by a direct comparison between the Delayed-mask condition in Experiment 2 (Figure 4A, filled symbols) and the 100-ms SOA condition in Experiment 3. The SOA in the two conditions was the same, but the mask was meaningful in Experiment 2 and meaningless in Experiment 3. A between-subjects ANOVA revealed a significant interaction effect between Lag and mask-meaningfulness, confirming that the two performance curves followed different time courses : (*F* (6, 348) = 5.32, *p* <.001, *MSE* = 174.14).

Before concluding the exposition of the empirical data, a curious coincidence should be noted. It pertains to the temporal course of performance in the Simultaneous-mask and No-mask conditions across all three experiments. Consider the 0-SOA curve in Figure 5: the trend over lags resembles that in an AB deficit. Namely, performance declined over the first three lags and it recovered thereafter. Similar trends can be detected in the Simultaneous-present curve in Figure 4B, and in the No-mask curve in Figure 2B. This raises the possibility that a minimal AB-like deficit may have occurred when the second target was masked with a simultaneous mask or when it was not masked at all. Admittedly, the effect of Lag was not statistically significant in any of these instances, and the U-shaped trend was entirely missing in the Simultaneous-mask curve in Figure 2B. Besides, the magnitude of the trend, when it occurred, was negligible in comparison to that obtained with delayed masks. Nevertheless, we felt that the coincidence was worth noting in case it reappears in future studies.

Summary of Experiments 1-3

The purpose of this chapter was to determine the role of masking of the second target in the AB deficit. Two different types of masks were used, delayed masks and simultaneous masks. In Experiment 1, delayed and simultaneous masks were compared to a more typical condition, where the number of items (i.e., masks) displayed after the second target co-varied inversely with the temporal lag between the first and second targets (stream mask). Identical ABs were observed when the second target was masked by a delayed mask and by a stream mask. In the simultaneous mask condition, however, no AB was observed. In Experiment 2, the two types of mask, delayed and simultaneous, were combined factorially. Again, an AB was observed with the delayed mask, but not the simultaneous mask. Moreover, the impairment observed in the simultaneous mask condition was not affected by the presence or absence of the first target. Also notable was that the two types of masks appeared to combine additively. The methodological difference between delayed and simultaneous masks is simply in the target mask SOA (delayed > 0; simultaneous = 0). Thus, in Experiment 3, the second target-mask SOA was parametrically varied. When the mask SOA was 0 (i.e., mask was simultaneous with the second target), no AB was observed. However, when the SOA was increased a family of AB curves was obtained, moving from a large AB at 50 ms to no AB at 100 ms. These results demonstrate that the role of masking of the second target during the AB is critical. The implications of this role are discussed in Chapter 3.

CHAPTER 3: VISUAL MASKING DURING THE ATTENTIONAL BLINK

Investigations of the AB deficit have concentrated primarily on variables that affect the processing of the first target. This is understandable because processing of the first target is essential for obtaining an AB deficit. The present work shows that variables that affect the processing of the second target are just as important. Two key findings emerged from the experimental work in Chapter 2. First, in order to obtain an AB deficit, the second target needs to be masked. Second, the form of masking is important: an AB deficit is obtained when the mask is delayed but not when it is presented simultaneously with the second target. To be sure, accuracy in identifying the second target is impaired whether the mask is simultaneous or delayed, but a second-target deficit time-locked to the first target is obtained only with delayed masking.

Two stages of processing

A comprehensive account of these results can be provided in terms of a two-stage model proposed by Chun and Potter (1995). In that account, processing is said to occur in two sequential stages. The first is a rapid detection stage, where potential targets are detected on the basis of specific features (e.g., colour, letter case) or on the basis of category. The second is a capacity-limited stage in which items are processed serially for subsequent report. Potential targets detected in Stage 1 gain access to Stage 2 only if the latter is not busy. If the second target arrives while Stage 2 is busy, it is delayed in Stage 1 until Stage 2 is free. During the period of delay, the representation of the second target is subject to deterioration through passive decay and through erasure by subsequent items. The representation becomes immune from deterioration once it is selected for further processing and for consolidation in Stage 2. The AB deficit is said to stem from the deterioration that occurs while the second target is delayed in Stage 1.

This account has proved capable of explaining the major findings in the AB literature. For example, it is known that the magnitude of the AB deficit increases with the difficulty of the first target (Chun & Potter, 1995). This is explained on the assumption that the period for which Stage 2 is kept busy with the first target increases as the target's difficulty is increased. In turn, the second target is delayed in Stage 1 for a correspondingly longer period, during which it is subject to deterioration. Another aspect of the results, which at first seems inconsistent with this account, can be explained on an additional assumption. Namely, a simple version of the two-stage model predicts that the AB deficit should be greatest at the shortest lag because, all other things being equal, the period of delay in Stage 1 should vary inversely with lag. Yet, it has been found that the second-target deficit is greatest not at the shortest lag (typically 100 ms) but at considerably longer lags. To account for this result, it has been hypothesized that, from the instant at which an item enters Stage 2, access is denied to subsequent items not immediately but gradually, over a period that is typically longer than 100 ms. Thus, when the second target is presented directly after the first, there is a finite probability that both targets may be processed concurrently in Stage 2. Similar principles governing the relationship between successive stimuli have been proposed by Raymond et al., (1992) and by Weichselgartner and Sperling (1987).

These temporal contingencies give rise to the U-shaped function over lags which is commonly found in AB experiments.

According to the two-stage model, there are two sources of deterioration for any given item in Stage 1: passive decay and erasure by temporally trailing items (Chun & Potter, 1995). The present results suggest that the main source of deterioration in Stage 1 is not passive decay but erasure by the item presented directly after the second target. Passive decay would be evidenced by an impairment at the shortest lag, followed by a gradual improvement over lags. Had passive decay been an important factor, this trend should have been observed in the No-mask condition in Experiment 1, and the Simultaneous conditions in Experiments 1 and 2, in which there were no trailing items to erase the second target. However, the salient curves in Figures 2B and 4B show little evidence of such a trend over the first few lags, suggesting that passive decay does not play a major role in the deterioration of the second target.

On the other hand, erasure -- or its absence -- provides a consistent account of the results obtained both with the simultaneous and with the delayed masks. With simultaneous masks, performance was impaired because the figural properties of the stimulus were impoverished, thus making it harder to extract the target from the noise. However, the impairment was not time-locked to the first target, namely, there was no evidence of an AB deficit. Within the two-stage model, this result can be explained by noting that the second target and its mask form a unitary stimulus which remains available in Stage 1 throughout the period of delay (i.e., while the first target is being processed in Stage 2) because there is no trailing stimulus to erase it. Thus, what gains access to Stage 2 after the delay is a unitary representation of the second target, albeit embedded in noise. In contrast, performance with delayed masks was clearly time-locked to the first target. Namely, performance was impaired at lags of 200 and 300 ms, and improved progressively thereafter. According to the two-stage model, performance was impaired at the shorter lags because the target was erased by the trailing mask during the period of delay in Stage 1. The probability that the second target could enter Stage 2 before being erased by the mask increased at the longer lags, and performance improved accordingly.

When the two forms of masking are combined, as was done in the Combined-mask condition in Experiment 2, the two-stage model provides a consistent account of the results. In that condition, the second target was either absent from the RSVP stream, or it was present, in which case it was embedded in a patch of dots and was followed by a single digit. When the first target was absent, overall performance was relatively low (Figure 4C), and no AB deficit was obtained. In terms of the two-stage model, the low level of performance was the result of a degraded stimulus gaining entry into Stage 2. Notably, entry was direct because, given the absence of the first target, Stage 2 was free. Thus, not having been delayed in Stage 1, the first target was never vulnerable to erasure, and an AB deficit was avoided. On the other hand, when the first target was present, not only was performance quite low, but it was clearly time-locked to the first target. This result is explained in the same terms as the results of the Delayed mask condition. Namely, while Stage 2 was occupied by the first target, the degraded second target was delayed in Stage 1. At the shorter lags, while delayed in Stage 1, the second target remained vulnerable to erasure by the delayed digit. At the longer lags, the probability that the second target could enter Stage 2 before being erased increased, and performance improved accordingly. This improvement in performance, however, could not exceed the level set by the simultaneous mask, namely the level achieved when the first target was absent from the RSVP stream.

Another finding that can be readily accommodated within the two-stage model is an asymmetry in the way in which the two targets may be masked in order to obtain an AB deficit. That is, we have shown that an AB deficit is obtained with delayed but not with simultaneous masking of the second target. In contrast, an AB deficit is obtained with either type of masking of the first target (Seiffert & Di Lollo, 1997). Why is type of masking important for the second target but not for the first? In the preceding discussion we have seen how the two-stage model accounts for the masking asymmetry in respect to the second target. The masking equivalence in respect to the first target is handled on the principle that any procedure that increases the difficulty of first-target processing will also increase the period for which Stage 2 remains busy, and therefore the period for which the second target remains vulnerable to erasure while delayed in Stage 1. This principle has been amply demonstrated by Chun and Potter (1995), and is supported by the negative correlation between level of performance on the first target and the magnitude of the AB deficit (Grandison, Ghirardelli, & Egeth, 1997; Seiffert & Di Lollo, 1997). It is plausible to expect that the difficulty of processing the first target was increased with either type of mask. The prolongation of Stage-2 processing then led to a longer delay for the second target with a corresponding increment in the probability of erasure and consequent AB deficit.

It is clear that the two-stage model can account adequately not only for the pattern of results obtained in the present work but also for the major results in the AB literature. We should note, however, that results obtained in some very recent studies may not be as readily interpretable, and that the model may need to be revised to accommodate them. Those findings, and their implications for the two-stage model, are reviewed below, after two alternative accounts of the AB deficit have been considered.

Alternative accounts

Two other accounts of the AB deficit have been proposed. One is based on competition amongst items in visual short-term memory (VSTM; Raymond, et al., 1992; Raymond, Shapiro, & Arnell, 1995). The other is based on the concept of attentional dwell time (Duncan et al., 1994). According to the competition model, not all items from the RSVP stream gain entry into VSTM. To enter VSTM, items must match pre-set templates corresponding to the two targets. This parallels the process of rapid detection (Stage 1) in the two-stage model (Chun & Potter, 1995). In addition, the items directly following the two targets also gain entry because of temporal contiguity. Items in VSTM are assigned weights in accordance with the goodness of match with their corresponding template. Finally, attentional resources are allocated to individual items according to two criteria: the item's weight, and the item's order of entry into VSTM. Thus, according to this scheme, the first target is assigned the largest amount of resources, and the item next to the second target receives the least. The finding that the AB becomes smaller as the inter-target lag is increased is explained as follows. If the lag is relatively short, the leading items (the first target and the next item) are still active in VSTM. This prevents sufficient attentional resources from being allocated to the second target, even though its weight is relatively high. In this case, an AB deficit occurs because the meager attentional resources allocated to the second target do not allow it to compete effectively with the other items in VSTM. Conversely, if the lag is long, decay of the first target in VSTM releases attentional resources that can be utilized for processing the second target, and the AB is reduced.

With reference to the present findings, the competition model would predict correctly that an AB deficit should be obtained with delayed masks because the mask itself would compete with the two targets in VSTM. The competition model would also predict a reduction in the AB deficit when the second target is not masked, because there would be no mask item in VSTM to compete with a representation of the second target. But there are at least two important aspects of the results that are problematic for the competition model.

First, the competition model has no provision for explaining why an AB deficit occurs with delayed masking but not with simultaneous masking of the second target. To be sure, this does not constitute disconfirmation, but it does show that the model is incomplete. This incompleteness is further emphasized by the predictions of the model that run afoul of the empirical results. For instance, the model predicts that items such as digit-masks which do not match the target template can nevertheless gain access to VSTM provided that they are presented in close temporal proximity to the target. The probability of the mask being admitted to VSTM diminishes as its temporal separation from target is increased. Thus, a simultaneous mask should gain access to VSTM far more easily than a delayed mask, because of its temporal contiguity with the target, and therefore produce a larger AB deficit than a delayed mask. This is the opposite of what was found.

A second finding that the competition model is strained to explain is that there were no significant differences between the Simultaneous-mask and the corresponding control condition in Figure 4B. The model would predict lower performance in the experimental than in the control condition based on the contents of VSTM on each condition. At a first approximation, VSTM in the experimental condition should contain about four items: the two targets, plus the item directly following each target. In contrast, VSTM in the control condition should contain only half that number of items because the first target is never presented. It follows that competition for retrieval of the second target in VSTM should be far greater -- and performance correspondingly lower -- in the experimental condition. But that was not the case.

In a more recent account of the AB deficit, Duncan et al. (1994; Ward, et al., 1996) have suggested that attention remains concentrated on the first target for several hundred ms before it can be shifted to the second target. During this attentional dwell time, the second target cannot be processed adequately, and its identification suffers correspondingly. This account shares broad similarities with that of Chun and Potter (1995) in that processing of the second target is said to suffer while the system is busy with the first target. However, in its present form, the account must be regarded as incomplete because it has no means of explaining why an AB deficit is obtained with delayed but not with simultaneous masks, or why no deficit is found if the second target is not masked.

Parallels between the AB deficit and masked priming

Throughout the present work, we distinguished between two masking processes: integration (peripheral) and interruption (central). Following convention (Bachmann & Allik, 1976; Breitmeyer, 1984; Scheerer, 1973; Spencer & Schuntich, 1970; Turvey, 1973), we instantiated the process of integration with simultaneous masks, and the process of interruption with delayed masks. An AB deficit was consistently obtained with delayed but not with simultaneous masking of the second target. We inferred from these results that an AB deficit occurs when the processing of the second target is disrupted by a trailing mask.

A logical next step is to consider what attributes of the target might be affected, and what stages of processing might be disrupted by the arrival of the mask. In the traditional view, backward masking is said to interfere with -- or terminate the processing of -- information at a precategorical level of stimulus representation (e.g., Scheerer, 1973; Turvey, 1973). The recent masking literature, however, suggests otherwise. The evidence (some of which is reviewed below) strongly suggests that, under conditions of backward masking, processing of the target can continue beyond precategorical levels to lexical and semantic levels. What appears to be disrupted by the mask is not precategorical information, but the kind of information needed for direct report of the stimulus. Much of the evidence comes from studies of a phenomenon known as masked priming, which is described below. Upon comparison, we found clear points of contact between the experimental literatures on masked priming and on the AB deficit. Below, we suggest that the two sets of outcomes may provide converging evidence towards an understanding of how backward masking affects stimulus processing and, more generally, how the visual system handles rapidly sequential inputs.

In conventional priming experiments, a brief display of a temporally leading word (the prime) facilitates the identification of a trailing target-word, provided that the two words are semantically related (Meyer, Schveneveldt, & Ruddy, 1975). This is taken as evidence that the semantic activation produced by the prime facilitates the processing of a semantically-related target. A similar stimulus sequence is used in masked-priming experiments, except that the prime is backward-masked so that the subject cannot report it. The fascinating and counterintuitive finding is that much the same type of facilitation is found in masked priming as in conventional priming experiments (Carr & Dagenbach, 1990; Cheesman & Merikle, 1986; Dagenbach, Carr, & Wilhelmsen, 1989; Marcel, 1983a; Marcel, 1983b). This equivalence of outcomes suggest that the prime is capable of producing semantic activation even if it is masked. In turn, as noted by

Marcel (1983b), this strongly suggests that backward masking disrupts the conscious registration of a stimulus but not its visual analysis.

A similar conclusion was reached on the basis of electrophysiological evidence in a recent study of the AB deficit. Luck, Vogel, and Shapiro (1996) recorded event-related brain activity during an AB experiment. They were particularly interested in the "N400" wave, whose amplitude increases with the degree of incongruity between a test word and its semantic context. The presence of an N400 wave indicates two things: first, that the test word was perceived as being incongruous with its semantic context. Second, and more important for the present purpose, that the test word had indeed been processed to a semantic level. In the study of Luck et al., the test word occupied the position of the second target in an RSVP stream, thus the subjects were unable to report it on at least some of the trials. Yet, the N400 component was very much in evidence when the semantic context was incongruous even when the subject was unable to report the test word. This strongly suggests that the second target was processed to a semantic level even though it could not be reported accurately. More important, this outcome suggests that what is disrupted in the AB deficit is the information required to make an overt identification response, not the information accrued in the course of processing the second target.

The parallel between masked priming and the AB deficit is compelling. In both paradigms, backward masking has been shown to disrupt the overt response to -- and perhaps the conscious registration of -- the target, but not its processing to high lexical and semantic levels. Bearing in mind that the evidence is suggestive rather than definitive, we can formulate a working hypothesis that masked priming and the AB deficit may be mediated by mechanisms with a good deal of communality. This hypothesis is strengthened by a second parallel between masked priming and the AB deficit, a parallel which stems from the main outcome of the present work. Just as the AB deficit is obtained with delayed but not with simultaneous masking of the second target, so does masked priming occur with interruption (central) but not with integration (peripheral) masking of the prime (Marcel, 1983a; Experiment 5).

These parallels justify -- and invite explicit testing of -- the hypothesis that masked priming and the AB deficit are different expressions of the same thing. A test that readily suggests itself is one in which the second target in an AB stream is used to prime a third target presented later in the stream. In fact, evidence for just this kind of priming has been reported by Shapiro, Driver, Ward, and Sorensen (1997) who found that the second target, even though unreportable because of its position in the RSVP stream, was capable of priming a third target presented shortly afterwards. That is, performance on the third target was better when the second and third targets were semantically related than when they were not. Thus, just as in masked priming, a sizable amount of information about the second target remained available within the system, even though the target itself could not be reported because it was backward-masked by the next item in the stream. Results entirely consistent with this conclusion have been reported by Maki, Frigen, and Paulson (1997). Pursuing the parallel between masked priming and the AB a step further, and bearing in mind the outcome of the present work, it should be expected that priming of the third target would occur when the second target is masked by interruption (as in Shapiro et al.'s study) but not when it is masked by integration. Such a study remains to be done.

A revised two-stage model

It can be inferred from the preceding evidence that, in studies of the AB, the information accrued during the visual analysis of the second target is not totally erased by a trailing mask. This creates a problem for the two-stage model proposed by Chun and Potter (1995). Especially intractable within the model is the finding of Shapiro et al. (1997) that a second target which cannot be reported accurately can nonetheless act as a prime for a third target. In considering how this might be handled within the two-stage model, the following question needs to be asked: If it is true that the second target could not be reported because it had been erased while waiting in Stage 1, how come it was still capable of priming a semantically-related third target?

As presently stated, the two-stage model cannot provide a plausible answer. A simple revision, however, enables the model to handle all the salient evidence. The revision introduces an intermediate stage which could be regarded as a holding buffer where the output of Stage 1 can be stored if Stage 2 is busy. Except for the addition of the holding buffer, the two-stage model would remain unchanged. Within this system, the sequence of processing events is as follows. Incoming stimuli are processed in Stage 1 in the manner proposed by Chun and Potter (1995). Namely, processing is in parallel and can include some lexical and semantic as well as sensory attributes of the stimulus. The encoded representation is then transferred to the holding buffer where it replaces (erases) the previous contents. The representation remains in the buffer until it gains access to Stage 2 or until it is replaced (erased) by the next input from Stage 1. In this fashion, a trailing mask can erase the representation of the second target in the holding buffer, but need not interfere with the residual activity of Stage-1 mechanisms that had been triggered while the second target was being processed at that level. It goes without saying that such residual activity may then be used to mediate priming of a third target. In passing, it is worth noting that although our suggestion of an intermediate buffer is speculative, it is not entirely ad hoc. Homologous intermediate stages between low-level processing and response programming have been proposed in earlier models. Two examples are the informational-persistence stage proposed by Irwin and co-workers (Irwin & Brown, 1987; Irwin & Yeomans, 1986), and the schematic memory buffer proposed by Di Lollo and Dixon (1988; Dixon & Di Lollo, 1991).

A broad parallel could be drawn between the revised two-stage model and the competition model of the AB (Raymond et al., 1995). Stages 1 and 2 in the two-stage model could be likened to the template-matching and the report stages, respectively, in the competition model. And the holding buffer in the revised two-stage model could be likened to the VSTM store. Beyond this superficial level, however, the parallel breaks down because, implicit in the revised two-stage model, is a stimulus-substitution theory of backward masking which differs sharply from competition in VSTM. That is, while delayed in the holding buffer, the representation of a leading target is vulnerable to erasure by a trailing mask. When that happens, the representation of the mask replaces that of the target in the buffer and eventually gains access to Stage 2. The upshot is that the mask is substituted for the target as the object for eventual conscious registration. This object-substitution account differs sharply from an account based on competition in VSTM. According to the competition model, the trailing mask is added to the contents of VSTM. This increases the number of items from which the target must be selected, and the probability of a correct response is reduced correspondingly. Thus, although both models postulate a temporary store, the processing events that take place within the store are vastly different in the two schemes.

A view of backward masking akin to object substitution was held by Marcel (1983b) who surmised that " ... at the relevant SOAs the [target] and the mask are parsed into the same [temporal] segment and the relative recency of the mask is sufficient to grant it figural status for recovery" (Marcel, 1983b, p. 269). This view is well supported in the masking literature. There is ample evidence to show that when two targets are presented sequentially at an optimal SOA, it is the second one which is perceived to the detriment of the first (Bachmann & Allik, 1976; Schiller, 1966). This effect has been found to be more pronounced in unattended visual locations, suggesting that stimuli displayed outside the focus of attention are more likely to be delayed in the holding buffer thus remaining vulnerable to substitution over a longer period (Enns & Di Lollo, 1997).

More important to the present argument, a tendency towards increased stimulus substitution has been obtained not only when attention is distributed over space (Enns & Di Lollo, 1997) but also when it is distributed over time, as in the AB deficit. This was revealed with remarkable clarity in two recent studies of the AB deficit (Chun, 1997; Martin, Isaak, & Shapiro, 1995). In the study by Martin et al. (1995), all items in the RSVP stream were alphabetical characters, with the two targets differing in size from the distractors. The principal issue under investigation was the nature of the errors made when the second target was identified incorrectly. It was found that the most common misidentifications of the second target arose from reporting the next item instead. In the study by Chun (1997), the task was to report coloured letter-targets presented among black-letter distractors. In agreement with the findings of Martin et al. (1995), Chun reported that the proportion of reports of the item directly following the second target increased during the AB. Both outcomes are concordant with the tenets of the revised two-stage model. In each case, the trailing item in the RSVP stream erased and replaced the second target while the latter was delayed in the holding buffer because Stage 2 was busy processing the first target. One might add that, according to the revised model, this process of substitution did not interfere with the pattern of activation that processing of the second target had produced in Stage 1. In accordance with the results of Shapiro et al. (1997), that activation could mediate priming of a related third target.

CHAPTER 4: VISUAL MASKING BY OBJECT SUBSTITUTION

Visual masking refers to the reduction in visibility of one stimulus, called the target, by another stimulus, called the mask, that is presented within close spatial and temporal proximity of the target (Breitmeyer, 1984). Research on visual masking has a long history dating back to the later part of the nineteenth century (e.g., Cattell, 1885) and has demonstrated that masking can be used to parse perceptual processes into different stages. In this spirit, the results reported in the previous chapter demonstrated that the internal representation of an unattended visual object is vulnerable to masking by a temporally-trailing, spatially-superimposed pattern. Behaviorally, it appears that the mask becomes the new focus of identification processes, such that the most common error of reporting an object under conditions of restricted attentional capacity is that of reporting the mask's identity (Chun, 1997; Isaak, Martin, & Shapiro, in press). Electrophysiological evidence suggests that the unattended target is processed to a semantic level, such that if the unattended target object does not match a predefined context, the semantic mismatch event-related potential (i.e., the N400) is not modulated during conditions of restricted attentional capacity (Luck, Vogel, & Shapiro, 1996; Vogel, Luck, & Shapiro, 1998). The pattern of behavioral data is suggestive of a substitution-type mechanism, whereby the representation of the target is replaced by that of the mask in the visual system. The electrophysiological data suggest that the disruption caused by the mask, substitution or otherwise, occurs after semantic processing.

Although the extant data regarding masking of unattended objects imply the disruption of high-level, post-perceptual mechanisms, the precise nature of the processes that are disrupted is not well defined. Characterizing the processes that are disrupted during conditions of restricted attentional capacity is essential for understanding the interactions between visual perception and attention and how a visually presented object emerges into awareness. As a first step towards addressing this issue, the experiments presented in Chapters 5-7 were designed to define the role of high-level object substitution mechanisms in masking of the second target during the AB. The aim of the present chapter is to determine whether masking effects observed in the AB are the result of the disruption of early, low-level processes or late, high-level visual processes.

Low-level vs. High-level Masking Effects

Visual masking effects can be broadly categorized into those that affect mostly low-level (early) visual processes and those that affect mostly high-level (late) visual processes. The distinction between low-level and high-level masking effects parallels Turvey's (1973) distinction between peripheral and central masking processes, respectively (e.g., masking by light would be considered a peripheral masking process, whereas masking by interruption would be considered a central masking process). Implied in this dichotomy is the notion that low-level and high-level masking effects are subserved by different mechanisms that have unique characteristics. It is beyond the scope of the present work to detail all the differences between low-level and high-level masking effects (for a detailed review see Breitmeyer, 1984), however, several of these unique characteristics are notable and are described below.

Low-level masking effects. These masking effects are contour dependent, such that the strength of the masking effect depends on the spatial proximity of adjacent contours, and/or the degree of similarity of overlapping contours. Low-level masking effects are also observed only under photopic (light-adapted viewing conditions) and are modulated by mask intensity (Spencer & Schuntich, 1970). The time-course of low-level masking effects is a relatively fast process, usually exhibiting its full force when the mask is presented within about 50 ms after the target (e.g., Breitmeyer, 1984). One particularly distinctive characteristic of low-level masking is that the effects are relatively insensitive to attentional manipulations (e.g., Spencer & Schuntich, 1970). Metacontrast masking exhibits many of the characteristics of a low-level masking effect because it is contour dependent (e.g., Enns & Di Lollo, 1997) occurs only under photopic viewing conditions (Bischof & Di Lollo, 1995), has a fast time-course, and is relatively unaffected by attentional manipulations, such as spatial uncertainty (e.g., Enns & Di Lollo, 1997; for a comprehensive review see Breitmeyer, 1984). Another example of a low-level masking effect is integration masking, described in the previous chapter. The strength of integration masking is sensitive to contour (Breitmeyer, 1984), is at a maximum when the target and the mask are presented simultaneously, and is not modulated by attentional manipulations (e.g., Spencer & Schuntich, 1970).

High-level masking effects. In contrast to low-level masking effects, high-level masking effects are not contour dependent, such that varying the spatial proximity of the mask contours relative to the target contours does not affect the strength of masking (e.g., Enns & Di Lollo, 1997). High-level masking effects are also largely independent of stimulus intensity and are observed under both photopic and scotopic (dark-adapted) viewing conditions (e.g., Di Lollo et al., 1999). The time-course of high-level masking effects is slower than that of low-level masking effects, such that the mask is most effective when it trails the target by about 50-150 ms (e.g., (Michaels & Turvey, 1973; Turvey, 1973). Also unlike low-level masking effects, high-level masking effects are modulated by attentional manipulations, such as the number of items in the display (e.g., Enns & Di Lollo, 1997; Spencer & Schuntich, 1970). One example of a high-level masking effect is interruption masking, described in the previous chapter. Another example is object substitution masking which is not contour dependent (Enns & Di Lollo, 1997) and occurs under both photopic and scotopic conditions (Di Lollo & Enns, 1998).

The distinction between low- and high-level masking effects is not a perfect one. To be sure, any particular form of masking most likely involves both low-level and high-level processes. For example, interruption masking is typically considered a high-level masking effect because it is sensitive to attentional manipulations (e.g., Spencer & Schuntich, 1970). However, interruption masking also has an low-level component in that the contours of the target and mask spatially overlap. In a similar vein, Bischof & Di Lollo (1995) demonstrated that a metacontrast mask is not effective under scotopic viewing conditions. Based on the descriptions above, this would place metacontrast masking in the low-level category. However, Ramachandran and Cobb (1995) suggest that metacontrast masking is also modulated by attention, which would place metacontrast masking in the high-level category. Thus, the distinction between low-level and high-level masking effects is a matter of degree. That is to say, that the processes that are disrupted by any particular form of masking will be mostly low-level processes, as in the case of metacontrast masking, or mostly high-level processes as in the case of object substitution masking.

Masking by object substitution

Enns & Di Lollo (1997) demonstrated that four small dots that surround, but do not overlap a target can act as a mask, but only when the target location is unattended. They argued that the representation of the mask "appears to be the new focus of object recognition mechanisms" (Enns & Di Lollo, 1997, p. 138). On this hypothesis, the authors refer to the form of masking observed with the 4-dot mask as object substitution masking, a term I will adopt here. The implicit assumption made by Enns & Di Lollo (1997) and by the hypothesis presented in the previous chapter is that object substitution is a high-level masking effect. Indeed, the very fact that a mere four dots, having minimal contour, can produce strong masking is suggestive of a high-level masking effect. In support of this view, object substitution masking is not affected by variables that modulate low-level masking effects, but is affected by variables that modulate high-level masking effects. This distinction between low-level and high-level effects with respect to object substitution is germane to the present thesis. Consequently, the pertinent results that support this distinction will be reviewed in the following paragraphs.

Object substitution masking has been observed in two paradigms. The main difference between these two paradigms is in the temporal relationship between the target and the mask. In one paradigm, used in the first published observation of masking by object substitution (Enns & Di Lollo, 1997), the duration between the onsets of the target and mask (stimulus onset asynchrony, SOA) varied randomly from trial to trial. In the second paradigm, the target and the mask had a common onset and the duration of the mask varied randomly from trial to trial (Di Lollo, Bischof, & Dixon, 1993; Di Lollo & Enns, 1998; Di Lollo, Enns, & Rensink, 1999). These paradigms will be referred to as the variable-onset and the common-onset paradigms, respectively.

Generally speaking, in both paradigms the effect object substitution is observed as the difference between conditions when the target location is attended versus when it is not attended. Moreover, the strength of masking also increases with increases in the distribution of spatial attention. However, as a consequence of the differences in the temporal parameters between the two paradigms, the precise effect of object substitution masking manifest somewhat differently. In the variable-onset paradigm, it appears as a change in performance in the unattended condition as a function of the SOA between the target and the mask. In the common-onset paradigm, the masking effect is manifest as a decline in performance with increasing mask duration. The characteristics of masking by object substitution will be reviewed in two sections; one section reviews key findings from experiments that used the variable-onset paradigm, the other reviews key findings from experiments that used the common-onset paradigm.

Variable-onset paradigm. In their initial work using the variable onset paradigm, Enns & Di Lollo (1997) directly compared object substitution masking to metacontrast masking. There were two conditions that differed only in the mask stimulus: In the metacontrast mask condition, the mask stimulus surrounded, but did not overlap, the target stimulus; in the four-dot mask condition, the mask stimulus consisted of four small dots placed at the corners of a notional square frame that surrounded, but did not overlap, the target. The target stimulus was a diamond with either the left or right corner missing and the task was to indicate which corner was missing. As mentioned previously, the SOA between the target and mask was varied.

Enns & Di Lollo (1997) reported four key characteristics of the four-dot mask that distinguish it from classical metacontrast masking and define it as a high-level masking effect. First, when the target location was known in advance, no masking was observed regardless of target-mask SOA. However, when the target location was randomly distributed between three possible locations, masking was observed with the four-dot mask, but masking was restricted to those cases where the target was presented in the periphery -- masking was not observed when the target was presented at fixation. These effects contrasted sharply with the metacontrast mask condition, where masking was observed when the target location was known in advance and regardless of whether the target occurred centrally or parafoveally. Second, when the distance between the target and four-dot mask contours was increased, the strength of masking did not change. This was true when the target was presented at fixation, where no masking was observed, and when the target was presented parafoveally, where masking was observed. Again, this was unlike the metacontrast mask, where the effect of target-mask proximity depended on where the target was presented: If the target was presented at fixation, then the strength of masking was inversely related to the distance between the target and mask contours; if the target was presented parafoveally, the strength of masking was not modulated by contour proximity. Third, the strength of four-dot masking was sensitive to the distribution of spatial attention, as modulated by the number of possible targets in the display: four-dot masking was more severe when there were three possible targets compared to when there was a single target in the display. Moreover, unlike when there was a single target in the display, when there were multiple targets, masking was observed at fixation. Metacontrast masking showed a different pattern of results. Namely, the strength of masking was not modulated by the number of targets in the display. Finally, across the experiments reported by Enns & Di Lollo (1997), four-dot masking was most effective when it was presented after the target, namely it was an effective backward mask. This was unlike the mask that completely surrounded the target, which was effective both as a forward (mask preceded target) and as a backward (i.e., metacontrast) mask, albeit it was more effective as a metacontrast mask.

Common-onset paradigm. Recently, the generality of object substitution masking has been tested using the common-onset paradigm, where the target and mask are presented simultaneously and the duration of the mask is varied (Di Lollo & Enns, 1998; Di Lollo, Enns, & Rensink, 1999). Under these conditions, the strength of masking increases as mask duration is increases. The advantage that this paradigm has over the variable-onset paradigm is that because of the common-onset of the target and mask, traditional feed-forward, onset-transient inhibitory explanations of masking are ruled out (e.g., Breitmeyer, 1984). More generally, the common-onset paradigm provides a more stringent test of whether object substitution masking affects mostly high-level processes.

Di Lollo and his colleagues (Di Lollo & Enns, 1998; Di Lollo, Enns, & Rensink, 1999) have demonstrated that the object substitution masking observed in the common-onset paradigm behaves similarly to that observed in the variable-onset paradigm. Namely, the strength of masking increases with the distribution of spatial attention as manipulated by the number of potential targets in the display (also called display *set size* in visual search experiments, e.g., Treisman & Gelade, 1980); and the strength of masking is independent of target-mask proximity. However, Di Lollo and Enns (1998; Di Lollo et al., 1999) also reported four new findings regarding the nature of masking by object substitution as observed in the common-onset paradigm. First, when the mask was a circle that surrounded, but did not overlap the target, masking was unaffected by adapting luminance -- the strength of masking was the same under photopic and scotopic viewing conditions. Thus, low-level inhibitory mechanisms do not mediate masking by object substitution. Second, when the mask consisted of four dots, the strength of masking was not reduced by simplifying the target task to simple feature detection rather than a difficult discrimination (e.g., Enns & Di Lollo, 1997). Third, the strength of masking was reduced, but not eliminated, by a so-called "pop-out" search task, where the target consists of a feature that is unique in the display (e.g., Treisman & Gelade, 1980). Finally, when the target was presented in random locations on the screen, but was always preceded by a valid spatial precue, object substitution masking was reduced. Interestingly, the benefit caused by the spatial precue depended on the SOA between the onset of the precue and the onset of the target display: At very brief SOAs very strong masking was observed, but the strength of masking declined as the SOA was increased.

Summary. Perhaps the most notable result emerging from the variable- and common-onset paradigms is that, regardless of paradigm, object substitution masking is modulated by the same variables. The most effective variable is the distribution of attention over space. As illustrated by the brief review, several “classical” manipulations of spatial attention can modulate masking by object substitution. These manipulations include display set size, spatial uncertainty, and spatial precuing. What is also notable about masking by object substitution is its resilience to “classical” manipulations of low-level visual processes. The symmetry between the results from the variable- and common-onset paradigms suggest that transient-onset inhibitory mechanisms do not play a role in this form of masking. Similarly, using a mask with minimal contour implies that low-level lateral inhibition does not cause the disruption of target processing. This conclusion is also supported by the independence between strength of masking and target-mask contour proximity. Finally, general low-level inhibitory processes are also ruled out as a factor because masking by object substitution is not affected by adapting luminance. Together, the data paint a clear picture of the nature of 4-dot masking, namely, the results characterize object substitution as a masking effect that disrupts high-level stages of visual processing.

CHAPTER 5: MASKING DURING THE ATTENTIONAL BLINK: INITIAL TESTS OF THE OBJECT SUBSTITUTION HYPOTHESIS

The findings of Chapter 2 demonstrated that during the AB, when attention is devoted to the processing of the first target, the representation of the second target is vulnerable to masking by a temporally-trailing, spatially-superimposed stimulus. The model that was presented to account for the results was based on the assumption that object substitution is responsible for the masking of an unattended second target. Moreover, two of the models of the AB that have been published since the original report of the results in Chapter 2 (i.e., Giesbrecht & Di Lollo, 1996) have incorporated explicitly the object-substitution hypothesis (e.g., Shapiro, Arnell, & Raymond, 1997b; Vogel, et al., 1998). But this proposal has not been tested directly. Indeed, the stimuli used to mask the second target in Chapter 2, and in all other studies of the AB, have distinct low-level components: the mask spatially overlaps the target and the onset transient in response to the mask is distinct from that in response to the target. Thus, low-level inhibitory masking effects can not be ruled out as an important factor. Nevertheless, the claim of the object substitution hypothesis is that these low-level components do not mediate masking of the second target duration the AB. That is to say, the hypothesis forces the prediction that if the low-level masking effects are ruled out, the AB should still be observed. On this rationale, the experiments reported in this and subsequent chapters tested the object-substitution hypothesis explicitly by using a 4-dot mask which allows one to rule out low-level masking effects and focus on masking by object substitution.

ExperimentalRationale

The experimental rationale is simple. If it is the case that masking of the second target is mediated by the same mechanisms that underlie masking by object substitution, then by modulating the strength of masking by object substitution, the AB should also be modulated. For example, if masking by object substitution is modulated by some manipulation and the second-target deficit is mediated by object substitution, then the second target deficit should also be modulated by the same manipulation. If this were to be true, then one can adopt the working hypothesis that during the AB the processes that are disrupted by a mask are those that are disrupted by object-substitution masking. This is exactly the hypothesis that emerged from Chapter 2. Moreover, it is what is predicted to be observed in the subsequent empirical work presented in this thesis. Namely, if masking by object substitution mediates masking of the second target, then modulating the strength of 4-dot masking should modulate the severity of the AB correspondingly.

On this rationale, variables that are known to modulate the strength of 4-dot masking were selectively manipulated. Enns & Di Lollo (1997; see also Di Lollo & Enns, 1998; Di Lollo et al., 1999) demonstrated that the strength of masking is modulated by the distribution of attention. They manipulated the distribution of spatial attention by presenting the target in unpredictable locations and by varying the display set size. Similar manipulations of spatial attention were employed here.

In addition to replicating previous investigations of masking by object substitution, the present work extends what is known about this form of masking by testing the generality of the phenomenon. As demonstrated by studies of the AB, attention can be distributed over time. Thus, by using the AB as a tool, one can investigate whether the strength of object substitution masking is modulated by manipulations that are not strictly spatial in nature. Thus, the purpose of the present experiments is to investigate the nature of the mechanisms involved in masking by object substitution and whether these processes are disrupted when an object is not the current focus of attention.

To anticipate the results, object substitution masking was modulated by the spatial distribution of attention, but was not modulated by the temporal distribution of attention. That is, although masking by object substitution was observed, an AB was not observed when the second target was masked by a 4-dot mask. This finding disconfirms the hypothesis presented in Chapter 2 and constrains many of the current models of the AB. More generally, the present results suggest that low-level, and not high-level, masking produces the AB.

EXPERIMENT 4

The experiments reported in this chapter used a conventional RSVP paradigm, similar to that used in Chapter 2. In this paradigm, each item was displayed for 32 ms, and was followed by the next item after a blank interval of 68 ms. Within the RSVP stream, the two targets were uppercase letters, and the distractors were digits of approximately the same size as the letters. The first target was always presented in the center of the screen, in the same location as the rest of the RSVP stream, and was always masked by the next item in the stream (e.g., Chapter 2; Raymond, et al., 1992). To measure the AB, the temporal separation between the first and second targets was systematically varied, and was either 100, 300, or 700 ms.

Enns and Di Lollo (1997) demonstrated the perceptability of a target of a target was severely degraded when that stimulus was backward masked by 4-dots. These authors argued that the mechanism underlying the masking effect was one of object substitution. This form of masking was distinguished from low-level forms of masking because it was sensitive to attentional manipulations, but not contour manipulations (i.e., amount of contour and contour proximity). The arguments presented in Chapter 3 suggested that masking during the AB was subserved by the same mechanisms. However, these arguments were based on the results when the second target was masked by a trailing digit. To provide a bridge between the Enns and Di Lollo (1997) paradigm and the paradigm used in Chapter 2, in Experiment 4 the second target was always backward masked by 4-dots. The SOA between the second target and the mask was the same as that between successively RSVP items: 100 ms. Thus, the only difference between this experiment and the delayed-mask conditions in Chapter 2 was in the form of the mask. In this manner, Experiment 4 represents a first step towards assessing mechanisms underlying masking of the second target during the AB.

To modulate the strength of object substitution, the location of the second target was varied. In different blocks of trials the second target and the mask were always presented in the same location as the rest of the stream (i.e., centrally) or they were presented at one of four locations just above, below, to the left, or to the right of the rest of the stream (i.e., eccentrically). Enns and Di Lollo (1997) found that when the a target is presented alone, masking by object substitution was only observed with the target was presented in random locations in the visual field. Thus, in the present experiment, comparison of the central and eccentric conditions tests for the presence of object substitution masking. Namely, if performance on the second target is found to be lower in the eccentric condition compared to the central condition, the difference can be ascribed to masking by object substitution. Moreover, this manipulation of spatial uncertainty allows for comparison of the relative roles of spatial and temporal distribution of attention in the masking of the second target.

Finally, in addition to the dual target conditions, single target control conditions were used. In these conditions, the first target was removed from the stream and replaced by a digit and the only target in the display was a letter target masked by four dots. Two control conditions were used, each corresponding to the second target central and eccentric conditions described above. Comparison of the experimental and control conditions tests whether an AB deficit occurred. Namely, if performance on the second target is found to be lower in the experimental than in the control conditions, the deficit can be ascribed to the effect of the first target. Thus, the study allowed for evaluation of the AB, masking by object substitution, and their interaction.

Method

Participants

Twenty-four undergraduate and graduate students (15 female) from the University of Alberta participated in this study and were paid $8 (modal age = 25). 20 of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Stimuli

All the stimuli used in this and subsequent experiments were displayed on a Tektronix 608 oscilloscope equipped with P15 phosphor. The viewing distance was 57 cm, set by a headrest. Alphanumeric stimuli subtended approximately .8° of visual angle. The distractor items were digits (0-9), and the target items were letters from the English alphabet. The 4-dot mask consisted of four small square patches (each .2° square). The dots were centred on the corners of a notional square (1° side). This notional square was centered on the same location on which the other RSVP stimuli were presented. With this arrangement, the contours of the dots did not overlap with the contours of any other stimuli. All stimuli had a luminance of 25 cd/m^2, as measured by a Minolta LS-100 luminance meter. The background and surrounding visual field were dark, except for dim illumination of the keyboard.

Procedure

At the beginning of each block participants were read the instructions appropriate for that block. At the beginning of each trial a small fixation dot was presented in the centre of the screen, indicating where the RSVP items would be presented. Subjects initiated each trial by pressing space bar. After a 500 ms delay, the RSVP stream was presented. Each item was displayed for 32 ms and was separated from the next item by a blank interstimulus interval (ISI) of 68 ms, yielding a presentation rate of 10 items/s. On any given trial, the distractors in the stream were selected randomly with replacement from the set of digits, with the constraint that the selected digit was not one of the two immediately-preceding items. The letter-targets were selected randomly without replacement from all letters of the English alphabet, excepting I, O, Q, and Z (these items were omitted due to their visual similarity to 1, 0, 2, and 7). The number of distractors preceding the first target was determined randomly on each trial and varied between 7 and 15. The second target and the 4-dot mask were always presented in the same location at the end of the stream. The durations of the second target and the mask were the same as the rest of the RSVP items, as was the ISI between the target and the mask. When the second target and the mask were eccentric, they were displayed so that the center of the letter was offset 1° from the rest of the stream. This ensured that no part of the second target frame (i.e., letter and mask) overlapped with the rest of the stream. A schematic representation of this paradigm is illustrated in Figure 6.

Insert Figure 6 about here

Participants were instructed to type their responses into the keyboard at their leisure. Participants were also instructed to be as accurate as possible, but to guess when necessary. In blocks in which both the first and second targets were to be identified, the responses could be entered in any order. After the instructions, participants were given an opportunity to ask questions and then did 15 practice trials to familiarize themselves with the task. After completing the test block of 96 trials, participants were given a rest break and then were given the instructions for the next set of trials.

Design

The experiment consisted of a single 1-hour session. The session was split in half, differing only in the location of the second target and the 4-dot mask. In one half, the second target and mask were presented in the center of the screen in the same location as the rest of the stream; in the other, the second target and mask were presented together above, below, to the left, or to the right of the rest of the RSVP stream. These conditions will be referred to as the Central and Eccentric conditions, respectively. In the Eccentric condition, the location of the second target and mask was randomized with the constraint that they were presented an equal number of times (four each) in each of the possible cardinal positions.

Within each T2-location condition there were two sets of trials, differing only in the number of letters that were present in the stream and that had to be identified. Just as described in Experiment 2 of Chapter 2, in one set the first target was present (Present set), in the other it was absent (Absent set). Again, for ease of terminology I refer to the only target in the Absent set as the second target because the only target in the Absent set and the second target in the Present set were presented in corresponding positions within the RSVP streams. That is to say, the streams in the Absent set were the same as in the Present set, except that the first target was replaced by a digit. Thus, the lag between the two targets in the Absent set should be regarded as the lag of the second target relative to when the first target would have been presented, had it been included in the stream.

The design resulted in four blocks of trials. Within each block of trials the temporal lag between the first and second targets was systematically varied. The second target was presented either 100, 300, or 700 ms after the first target. These lags will also be referred to as lag 1, lag 3, and lag 7, respectively. In the Eccentric condition, when the second letter was presented at the first lag, a digit was also presented in the center of the screen so as to mask the first target. The second target was presented 32 times at each of the three lags, resulting in four blocks of 96 trials. Participants did 15 practice trials at the beginning of each of the 4 blocks of trials.

Conditions were counter balanced as follows. Half of the participants received the Eccentric condition first and half the Central condition first. In each case, half received the Present set first and half received the Absent set first. This resulted in 8 possible orders of first target present or absent (P/A) and second target location (Central and Eccentric). Three subjects were run in each of the eight orders. The order of presentation of the mask duration and T1-T2 lag conditions was randomized within a block of trials.

Noise dots

Pilot studies that used a paradigm similar to that described above revealed that the second target task was prone to ceiling effects, where accuracy was above 90% in all conditions. To prevent the possibility of ceiling effects confounding the results, second target accuracy was lowered through the use of noise dots that were presented simultaneously with the second target and that overlapped the second target. This approach was adopted on the basis that it was likely that degrading the visual display with noise dots would not interact with the variables of interest (in this case first target P/A and temporal lag). This assumption was grounded on two empirical results. First, the results of Chapter 2 demonstrated that integration masking is independent of manipulations of first target P/A and temporal lag. Second, the work of Enns & Di Lollo (1997) demonstrate that 4-dot masking is independent of low-level effects, such as the masking caused by integrationmasking.

The objective of adding noise dots to the second target display was to lower overall accuracy of identification of the second target so that it would fall within a 20% range center on the middle of the response scale. In this task, ceiling was 100% and chance was 5%, thus the middle of the response scale is approximately 52% and the range for accuracy was between 42% and 62%. The reduction of second target identification accuracy was achieved by presenting noise dots that overlapped the second target. These dots were smaller than the dots of the 4-dot mask and had a luminance of 25 cd/m^2. The dots were placed in random positions within the .8° notional frame within which the second target was presented. The number of dots was adjusted after every 24 trials. If accuracy of identification of the second target was below 42%, the number of dots was reduced by 10; if accuracy was above 62%, the number of dots was increased by 10; and if accuracy was between 62% and 42%, the number of dots was not changed. This method of constraining the level of second target identification accuracy was used in this and subsequent experiments.

The starting number of dots for each block was 20. The mean number of dots in each block collapsed across all subjects were as follows: Present-Central, 24; Present-Eccentric, 18; Absent-Central, 24; Absent-Eccentric, 20. The range for the Central and Eccentric conditions was the same whether the first target was present or absent: Central (Present and Absent), 0-50; Eccentric (Present and Absent), 0-40.

Results

Prior to the exposition of the empirical data several details regarding the analysis must be noted. In this and subsequent experiments reported in this chapter, estimates of second target identification accuracy are based on those trials in which the response to the first target was correct. As discussed in Chapter 2, this is a practice that is commonly adopted in AB experiments on the grounds that, on incorrect trials, the source of the error is unknown, so its effect on second-target processing cannot be estimated. Similarly, in this and subsequent experiments reported in this chapter, I adopt the same procedure for plotting second target accuracy in the Absent conditions as used in Experiment 2 in Chapter 2. Namely, for the sake of comparison with the Present condition, notional lags can be devised, based on the way in which the RSVP streams were constructed. To wit, the Present and Absent streams differed in a single detail: in the latter, the first target letter was replaced with a digit. Therefore, notional inter-target lags can be specified for the Absent conditions in terms of the temporal interval that elapsed from the presentation of the digit that replaced the first target and the presentation of the second target on any given trial. Constructing the streams in this manner controls for the number of stream items presented before the second target.

The final detail regarding the analysis is perhaps the most important. In the present experiment, the second target was presented in the same location as the rest of the RSVP stream or it was presented at an eccentric position. This manipulation of spatial uncertainty presents a problem for analysis of the data. Namely, in one condition the second target is always in the center of the screen and in the other the second target is not. Thus, switching spatial locations may affect performance independently of the AB or masking by object substitution. Thus, tantamount to understanding any difference between conditions where the second target is always in the center of the screen and conditions where the second target is always in an eccentric location, is the understanding the role of spatial switching in the AB. Recently, Visser and his colleagues (Visser, Bischof, & Di

Lollo, in press-a) conducted a meta-analysis of the AB literature that addressed this issue. A nagging problem in the AB literature is that some experiments observe nonmonotonic U-shaped functions across temporal lags (such as those observed in Chapter 2), whereas other experiments show monotonic functions across lags. The difference between these two functions is the different levels of accuracy at the first lag. When accuracy is higher at lag 1 compared to lag 2, performance at lag 1 is said to be "spared". Following Potter and her colleagues (Potter, Chun, Banks, & Muckenhoupt, 1998), I refer to this as lag-1 sparing. Visser et al. (in press-a) demonstrated that lag-1 sparing is largely dependent on the spatial relationship between the first and second targets: Namely, when the two targets were in the same location lag-1 sparing was observed, but when they were in different locations lag-1 sparing was not observed. More importantly for the present purpose, the temporal course of the AB after lag 1 was the same regardless of the spatial relationship between the first and second targets (see also (Visser, Zuvic, Bischof, & Di Lollo, in press-b). Moreover, these authors demonstrated that the magnitude of lag-1 sparing was not related to the magnitude of AB. Thus, the effect of spatial switching is to reduce performance at the first lag and the mechanisms underlying this effect are not related to the mechanisms underlying the AB at subsequent lags. Consequently, the evaluation of the presence or absence of AB must be based on analysis of lags after lag 1, thereby omitting any contamination by the effect of spatial switching. On this analysis, all the conclusions in this thesis are based on the results of the analyses that omit lag 1.

Although the issue of the relationship between lag-1 sparing and the AB may be contentious, the results of Visser et al. justify the present approach. Moreover, Experiment 9 provides further justification of this approach. For the sake of completeness, however, the results of this and subsequent experiments will be divided into two sections. The first section is the analysis of second target identification accuracy including lags 3 and 7 only; the second section is the analysis of second target identification accuracy including all lag conditions. Within these two sections, the results for the Central and Eccentric conditions are analysed separately, comparing first target Present and Absent conditions. Then the Present sets of the Central and Eccentric conditions are compared directly.

Lags 3-7

Central. Mean percentage of correct identifications of the first target, collapsed across lags was 91.7. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel A of Figure 7. There were two main results. First, overall accuracy of identification of the second target was slightly higher in the Absent condition (56.2%) than in the Present condition (54.5%). Second, there was no interaction between first target P/A and lag: In both the Present and Absent conditions there was a very slight improvement in accuracy from lags 3-7.

Insert Figure 7 about here

The results in Panel A of Figure 7 were reanalysed in a 2 (first target: P/A) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. Only the main effect of P/A was significant, $F(1, 23) = 13.2$, $p < .002$, $MSE = 66.6$. The main effect of Lag was not significant, $F(1, 23) = 3.25$, $p > .08$, $MSE = 71$; nor was the P/A x Lag interaction, $F < 1$.

Eccentric. Mean percentage of correct identifications of the first target, collapsed across lags was 92.8. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel B of Figure 7. There were two main results. First, accuracy of identification of the second target did not depend on whether the first target was present or absent (Present = 54.8%; Absent = 52.2%). Second, there was no interaction between first target P/A and lag.

The results in Panel B of Figure 7 were analysed in a 2 (first target: P/A) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. None of the effects proved to be statistically reliable: first target P/A, $F(1, 23) = 1.68$, $p > .21$, $MSE = 103.32$; Lag, $F(1, 23) = 1.56$, $p > 22$, $MSE = 65.9$; P/A x Lag interaction, $F(1, 23) = 2.05$, $p > .16$, $MSE = 86.76$.

Combined and Eccentric combined. When the Present-Central and -Eccentric conditions (filled symbols in Panels A and B of Figure 7) are compared there are three notable results. First, overall accuracy was the same in the two Location conditions (Central: 54.1%; Eccentric: 54.8%). Second, in both conditions there was an effect of lag, with accuracy slightly lower at lag 3 than at lag 7 (52.3% and 56.6%, respectively). Finally, the lag effect was very similar in both location conditions.

These data were analysed in a 2 (Location: Central or Eccentric) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. As suggested by the descriptive analysis, the only statistically significant effect was that of Lag, F(1, 23) = 6.13, p < .03, MSE = 73.2. Both the effect of second target location and the Location x Lag interaction had F's < 1.

All lags

Central. Mean percentage of correct identifications of the first target, collapsed across lags was 90.1. The results were reanalysed in a 2 (first target: P/A) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. As with the analysis that included only lags 3-7, the main effect of P/A was statistically significant, F(1, 23) = 12.78, p < .002, MSE = 58.2. Similarly there was no main effect of Lag, F(2, 46) = 1.88, p > .16, MSE = 69.11; or a P/A x Lag interaction, F(2, 46) = 1.35, p > .27, MSE = 65.86.

Eccentric. Mean percentage of correct identifications of the first target, collapsed across lags was 90.8. The results reanalysed including all lags. Both the main effect of Lag and the P/A x Lag interaction were statistically reliable: Lag, F(2, 46) = 10.24, p < .001, MSE = 74.62; . P/A x Lag, F(2, 46) = 4.36, p < .02, MSE = 95.52. The main effect of first target P/A was not significant (F < 1).

Combined and Eccentric combined. These data were reanalysed in a 2 (Location: Central or Eccentric) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. Unlike the analysis that included only lags 3-7, all effects were significant. There was a significant main effect of Location, F(1, 23) = 5.56, p <

.03, MSE = 107.29; Lag, $F(2, 46) = 7.19$, $p < .002$, MSE = 66.6; Location x Lag, $F(2, 46) = 8.27$, $p < .001$, MSE = 100.98.

Discussion

The rationale for this experiment was simple: replicate the delayed mask conditions from Chapter 2 using a 4-dot mask. The object substitution hypothesis predicts that an AB should have been observed. In contrast to the prediction, no AB was observed. This was true whether the second target was presented centrally or eccentrically. Thus, these results suggest that the object substitution hypothesis should be rejected. However, rejecting the object substitution hypothesis based on these results would be premature.

In order to confidently reject the hypothesis that object substitution does not mediate masking of the second target during the AB, one must demonstrate that object substitution masking was observed. In the present experiment, evidence for the presence of object substitution masking would be found by lower mean second target accuracy in the Eccentric condition compared to the Central condition. Although performance was reliably lower when the second target was eccentric than when it was central, the magnitude of the difference was <10%. That is to say, although there was evidence of object substitution, the effect of masking was small. Consequently, one can not confidently reject the object substitution hypothesis. Indeed, the hypothesis may only be rejected when object substitution masking is observed in its full force. Experiments 5 and 6 were designed to provide a more powerful test of the hypothesis by increasing the strength of the 4-dot mask.

EXPERIMENT 5

In Experiment 4, the object-substitution hypothesis of masking during the AB was tested by using 4-dots to backward mask the second target. Although the AB was not observed, the object substitution hypothesis could not be rejected because only a minimal masking effect was observed.

The rationale for Experiment 5 is the same as that for Experiment 4. Namely, to assess the role of high-level mechanisms underlying object substitution and whether they mediate masking during the AB deficit, the second target was always masked by a 4-dot mask. Unlike Experiment 4, however, the second target and 4-dot mask were always presented simultaneously, as in the common-onset paradigm (e.g., Di Lollo et al., 1993). An advantage of the common-onset paradigm is that in addition to ruling out low-level mechanisms through reducing the amount of contour in the mask, low-level mechanisms are also ruled because of the temporal relationship between the target and the mask. More specifically, because the target and mask are presented simultaneously, inhibitory transient mechanisms locked to the onset of the mask cannot hinder the perceptibility of the target. Thus, using the common-onset paradigm allowed for a stronger test of the object substitution hypothesis.

Experiment 5 was similar to Experiment 4 in most respects: the second target and mask were presented either centrally or eccentrically, and the first target was either present or absent. The only difference was in Experiment 5, the second target and mask had common-onsets. In addition, the duration of the mask was systematically varied and was either the same duration as the target (32 ms) or it was 600 ms. Comparison of the duration conditions tests whether object substitution occurred (i.e., a deficit in the 600 ms condition compared to the 32 ms condition). The prediction was the same as Experiment 4: To the extent that high-level object substitution mechanisms mediate masking of the second target an AB should be observed.

Method

Participants

Twenty-four undergraduates (22 female) from the University of Alberta subject pool participated for class credit (modal age = 19). Nineteen of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure

The procedure for Experiment 5 was the same as Experiment 4 in most respects. The only difference was that the target and mask were always presented simultaneously and the duration of the mask was systematically varied (see Design).

Design

The design of this experiment similar to Experiment 4 in most respects. Namely, the location of the second target (Central or Eccentric) and first target P/A were factorially combined, resulting in four blocks of trials. Within each block the second target was presented at lags 1, 3, and 7. The only addition to the design was that within each block the duration of the 4-dot mask was either 32 ms (i.e., same as the second target) or it was 600 ms. Counterbalancing was carried out as in Experiment 4.

Participants did 15 practice trials at the beginning of each of the 4 blocks of trials. Each test block consisted of 16 trials in each lag condition, 48 trials per dot duration condition and four blocks of 96 trials.

Noise dots

In each block of the experiment subjects began with 80 dots. The mean number of dots in each block and the minimum and maximum number of dots (presented in brackets) in each block, collapsed across all subjects were as follows: first target Present-second target Central, 86 (50-110); Present-Eccentric, 75 (50-110); Absent-Central, 85 (50-110); Absent-Eccentric, 78 (50-100).

Results

Lags 3-7

Central. Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 89.6; 600 ms, 91.8. Dynamically varying the number of noise dots simultaneously presented with the second target had the desired effect: mean percentage of correct identifications of the second target collapsed across all conditions shown in Panel A of Figure 8 was 58.2. Thus, any of the results reported here are not artifacts due to performance being at ceiling. Overall, there appeared to be no difference between the Present and Absent conditions (filled vs. open symbols) nor a difference between lags 3 and 7. Mask duration had an effect on performance, such that overall, accuracy was lower in the 600 ms condition (54.7%) than in the 32 ms condition (60.5%). This difference did not appear to change as a function of Lag, nor as a function of first target P/A.

Insert Figure 8 about here

The results in Panel A of Figure 8 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. The only statistically significant effect was the main effect of Duration, $F(1, 23) = 10.25$, $p < .005$, $MSE = 156.12$. All other main effects and interactions were not significant (all F's < 1.07, p's $> .05$).

Eccentric. Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 93.8; 600 ms, 93.9. As in the Central condition, dynamically varying the number of noise dots was successful in bringing accuracy down off of the percent correct response scale: mean percentage of correct identifications of the second target collapsed across all conditions shown in Panel B of Figure 8 was 50.1. Overall accuracy was better in the Absent than in the Present condition (53.3% vs. 48.9%), but this advantage for the Absent condition appeared only at lag 1. Mask duration had an effect on performance, such that in both the Present and Absent conditions, accuracy was lower in the 600 ms condition (46.9%) than in the 32 ms condition (58.2%). Within the P/A conditions, the effect of Duration did not change as a function of lag.

The results in Panel B of Figure 8 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. As with the analysis of the Central condition the main effect of Duration was significant, F(1, 23) = 41.69, p < .001, MSE = 145.08. In addition, there was also a main effect of Lag, F(1, 23) = 11.35, p < .003, MSE = 111.31; and a significant P/A x Lag interaction, F(1, 23) = 6.49, p < .02, MSE = 123.56. The remaining effects were not statistically significant: first target P/A, F < 1; P/A x Duration, F(1, 23) = 1.62, p > .21, MSE = 131.72; Duration x Lag, F < 1; P/A x Duration x Lag, F(1, 23) = 3.53, p > .07, MSE = 114.24.

Central and Eccentric combined. When the Present-Central and Present-Eccentric conditions (filled symbols in Panels A and B of Figure 8) are compared there are two notable results. First, overall accuracy was roughly similar in the two Location conditions (Central: 57.2%; Eccentric: 53.4%). Second, in both conditions there was an effect of mask duration, with lower accuracy in the long duration mask condition, but the masking effect was larger in the Eccentric condition.

These data were analysed in a 2 (Location: Central or Eccentric) x 2 (Duration: 32 or 600 ms) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. There was a significant main effect of Duration, $F(1, 23) = 22.77$, $p < .001$, $MSE = 188.17$; and of Lag, $F(1, 23) = 10.26$, $p < .005$, $MSE = 169.79$; but, as suggested by visual inspection of the data shown in Figure 8, there was not a significant main effect of Location, $F(1, 23) = 2.48$, $p > .13$, $MSE = 274.38$. In addition, there were two interactions that were significant: Location x Duration, $F(1, 23) = 5.92$, $p < .03$, $MSE = 122.59$; Location x Lag, $F(1, 23) = 4.78$, $p < .04$, $MSE = 102.57$. Finally, the Duration x Lag interaction was not significant, $F(1, 23) = 3.6$, $p > .07$, $MSE = 13.24$; nor was the 3-way Location x Duration x Lag interaction, $F < 1$.

All lags

Central. Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were 88.9 when the mask duration was 32 ms and 92.4 when the duration was 600 ms. The results in Panel A of Figure 8 were reanalysed including all lags. The only effect that was significant beyond the .05 level was the main effect of Duration, F(1, 23) = 14.2, $p < .002$, MSE = 158.8. All other main effects and interactions were not statistically significant: P/A, $F < 1$; Lag, F(2, 46) = 1.13, $p > .33$, MSE = 160.02; P/A x Duration, $F < 1$; P/A x Lag, F(2, 46) = 2.24, $p > .12$, MSE = 159.27; Duration x Lag, $F < 1$; P/A x Duration x Lag, $F < 1$.

Eccentric. Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 91.5; 600 ms duration, 91.7. The results in Panel B of Figure 8 were reanalysed in a 2 (first target: P/A) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. This analysis revealed a different pattern of results compared to the Central condition. All three main effects were statistically significant: first target P/A, F(1, 23) = 15.25, $p < .001$, MSE = 198.54; Duration, F(1, 23) = 65.58, $p < .001$, MSE = 168.82; Lag, F(2, 46) = 19.65, $p < .001$, MSE = 119.92. The only statistically significant interaction was the P/A x Lag interaction, F(2, 46) = 41.01, $p < .001$, MSE = 127.64. All other interactions were not significant: P/A x Duration, F(1, 23) = 1.3, $p > .26$, MSE = 164.93; Duration x Lag, $F < 1$; P/A x Duration x Lag, F(2, 46) = 1.52, $p > .22$, MSE = 139.33.

Central and Eccentric combined. Visual inspection of the Present conditions shown in Panels A and B of Figure 8 (filled symbols) reveals that overall, identification accuracy was lower in the Eccentric than in the Central condition. This was especially true at lag 1. In addition, the long duration 4-dot mask was more effective in the Eccentric than in the Central condition. These data were reanalysed in a 2 (Location: Central or Eccentric) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. All three main effects were statistically significant: first target Location, $F(1, 23) = 21.4$, $p < .001$, $MSE = 484.44$; Duration, $F(1, 23) = 33.37$, $p < .001$, $MSE = 206.97$; Lag, $F(2, 46) = 15.67$, $p < .001$, $MSE = 163.75$. In addition, there were two reliable interactions: Location x Duration, $F(1, 23) = 7.7$, $p < .02$, $MSE = 175.36$; Location x Lag, $F(2, 46) = 50.92$, $p < .001$, $MSE = 100.74$. The remaining interactions were not significant: Duration x Lag, $F(2, 46) = 1.52$, $p > .22$, $MSE = 166.01$; Location x Duration x Lag, $F < 1$.

Discussion

There were two notable results emerging from Experiment 5. First, in the Central condition, there was an effect of mask duration, but no difference between the first target present and absent conditions. Second, in the Eccentric condition, there was also an effect of mask duration; in addition, although there was no overall difference between the present and absent conditions, the effect of temporal lag differed in the two conditions. These results are germane to the present purpose and deserve further consideration.

The hypothesis put forth in Chapter 2 states that while attention is devoted to the first target the representation of the second target remains vulnerable to object substitution by a temporally-trailing, spatially-superimposed stimulus. The Central condition provides the most direct test of this hypothesis because the second target and mask were presented in the same location as the rest of the RSVP stream. There was a small effect of mask duration, despite the fact that the target location was known in advance. However, second target performance did not change as a function of lag or attentional load (i.e., first target P/A). In other words, masking by object substitution was observed, but there was no AB. Thus, it appears that the object substitution account of the AB is disconfirmed. However, as with the results of Experiment 4, the strength of masking was relatively small (<10%); perhaps too small to produce the AB.

In contrast to the small effect of mask duration in the Central condition, there was a large effect of mask duration in the Eccentric condition. In addition, there was also an effect of lag. This was most apparent in the 600 ms duration condition (see Figure 8, circles), whereas in the 32 ms condition there was no difference between the effect of lag in the Present and Absent conditions. Based on these results, it is clear that object substitution was observed, thereby replicating the results of Di Lollo and his colleagues (Di Lollo et al., 1999). There also appears to be an AB, especially when considering the 600 ms condition. Both of these results, namely the observation of object substitution masking and the AB, are notable for accounts of object substitution masking and the AB, and will be discussed further in the General Discussion. The most important point for the present time is that when strong object substitution masking is observed, an AB is observed, thus supporting the hypothesis presented in Chapter 2. However, the support for the object substitution hypothesis is not unequivocal because in the 32 ms condition, there was no difference between the Present and Absent conditions. That is, there was an AB in only one condition. So the results of

Experiment 5 are, at best, suggestive of support for the object substitution account of masking during the AB.

EXPERIMENT 6

In Experiment 5, when the second target and mask were presented at the end of the RSVP stream, they comprised the complete display. Regardless of the location of the second target, masking by object substitution was observed. However, it is possible that the displays in Experiment 5 were not optimal for masking by object substitution.

Enns & Di Lollo (1997) demonstrated that masking by object substitution is only observed when attention is distributed over space. In the present experiment, this was achieved by presenting the second target and mask together in random positions on the screen (i.e., Eccentric condition). However, when the combined stimulus of the target and the mask was presented it was the only abrupt onset in the visual field. It has been well demonstrated that onsets of this sort may automatically capture spatial attention (Jonides & Yantis, 1988; Yantis & Jonides, 1990). Thus, it is possible that on a proportion of trials, presenting the second target alone in the periphery may have automatically captured attention, thereby attenuating masking by object substitution.

One approach to preventing the automatic capturing of attention by an abrupt onset is to present distracting stimuli simultaneously with the target stimulus. With simultaneous presentation of a target with distractors there is nothing unique to the target/mask onset, and therefore attention cannot be drawn to it alone. This way, attention is distributed over space. Moreover, increasing the number of stimuli presented on the screen with the target amounts to a set size manipulation used to increase attentional demand in visual search experiments (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1994). Thus, adding distractors both eliminates the possibility that the target/mask will attract attention as a single abrupt onset, and it also increases the set size. Together this manipulation should increase the attentional demand of the task and, within the present context, increase the strength of masking by object substitution (Di Lollo et al., 1999; Enns & Di Lollo, 1997).

Experiment 6 is an exact replication of Experiment 5 with one exception: when the second target and mask were presented eight digits were also presented. The display of the second target and distractors was arranged in an imaginary 3 x 3 grid (i.e., no grid-lines were visible). The RSVP stream was presented in the center position of the grid. In the Central condition, the second target and mask were also presented in the centre location and digits filled the remaining eight grid locations. In the Eccentric condition, the second target and mask were presented in the grid locations that were above, below, to the left, or to the right of the centre location and digits filled the other eight locations. A schematic representation of the second target display is shown in Figure 9. Otherwise the design of the experiment was exactly the same as in Experiment 5. To the extent that increasing the set size of the second target display increases the distribution of spatial attention, the expectation was that masking by object substitution would be observed and consequently an AB would also be observed.

Insert Figure 9 about here

Method

Participants

Twenty-four undergraduates (21 female) from the University of Alberta subject pool participated for class credit (modal age = 19). All of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure

The procedure used in Experiment 6 was the same as Experiment 5, where the second target and the mask were presented either centrally or eccentrically. The only difference was that in Experiment 6, when the second target and the mask were presented, 8 digits were also presented. The digits were selected randomly with replacement from the digits from 0-9. The second target, the mask, and the 8 digits were presented in a 3 x 3 grid centered on the screen, such that the center position of the grid was in the same location as the rest of the RSVP stream. The distance between the center of the middle location and the center of the cardinal positions was 1°. The second target display was approximately 3° x 3° in size. The display configuration is shown in Figure 9.

Design

The design of this experiment was exactly the same as Experiment 5.

Noise dots

In each block of the experiment subjects began with 70 dots. The mean number of dots in each block and the minimum and maximum number of dots (presented in brackets) in each block, collapsed across all subjects were as follows: first target Present-second target Central, 76 (50-100); Present-Eccentric, 67 (540-90); Absent-Central, 79 (50-100); Absent-Eccentric, 69 (40-90).

Results

Lags 3-7

Central. Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 92.2; 600 ms, 93.4. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel A of Figure 10. As in Experiment 5, there appeared to be no difference between the Present and Absent conditions (filled vs. open symbols) nor a difference between lags 3 and 7. Mask duration had an effect on performance, such that overall, accuracy was lower in the 600 ms condition (57.8%) than in the 32 ms condition (64.4%). The difference between the duration conditions was larger at lag 3 (10.6%) than at lag 7 (2.5%).

Insert Figure 10 about here

The results in Panel A of Figure 10 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. There were two statistically significant effects: Duration, F(1, 23) = 13.83, $p < .002$, MSE = 149.2; and Duration x Lag, F(1, 23) = 4.81, $p < .04$, MSE = 162.55. All other main effects and interactions were not significant (all F's < 1).

Eccentric. Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 92.4; 600 ms, 92.8. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel B of Figure 10. As in the Central condition, there was no difference between Present and Absent conditions. Mask duration had an effect on performance, such that in both the Present and Absent conditions, accuracy was lower in the 600 ms condition (44.0%) than in the 32 ms condition (56.6%). Within the P/A conditions, the effect of Duration did not change as a function of lag.

The results in Panel B of Figure 10 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. As with the analysis of the Central condition, the only statistically significant main effect was that of Duration, F(1, 23) = 39.5, $p < .001$, MSE = 192.4. All remaining effects were not statistically significant:

first target P/A, F (1, 23) = 1.52, p > .23, MSE = 104.91; P/A x Lag, F(1, 23) = 3.04, p > .09, MSE = 160.01; all other F's < 1.

Central and eccentric combined. When the Present-Central and Present-Eccentric conditions (filled symbols in Panels A and B of Figure 10) are compared there are two notable results. First, overall accuracy was better in the Central than in the Eccentric condition (Central: 57.2%; Eccentric: 53.4%). Second, in both conditions there was an effect of mask duration, where accuracy was lower in the long duration mask condition than in the short duration mask condition, but the masking effect was larger in the Eccentric condition.

The Central and Eccentric conditions were compared directly in a 2 (Location: Central or Eccentric) x 2 (Duration: 32 or 600 ms) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. There was a significant main effect of Location, F(1, 23) = 29.14, p < .001, MSE = 260.97; and of Duration, F(1, 23) = 30.26, p < .001, MSE = 169.96; but not of Lag, F(1, 23) = 2.19, p > .15, MSE = 128.42. None of the interaction effects were statistically significant beyond the .05 level: Location x Duration, F(1, 23) = 2.96, p > .09, MSE = 211.98; Location x Lag, F(1, 23) = 1.06, p > .32, MSE = 116.36; Duration x Lag, F(1, 23) = 3.01, p > .09, MSE = 121.5; Location x Duration x Lag interaction, F < 1.

All lags

Central. Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 91.1; 600 ms duration, 91.7. The results in Panel A of

Figure 10 were reanalysed in a 2 (first target: P/A) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. The only effect that was significant beyond the .05 level was the main effect of Duration, $\underline{F}(1, 23) = 21.09$, $\underline{p} < .001$, $\underline{MSE} = 142.8$. All other main effects and interactions were not statistically significant: P/A, $\underline{F}(1, 23) = 2.35$, $\underline{p} > .13$, $\underline{MSE} = 111.81$; Lag, $\underline{F}(2, 46) = 1.68$, $\underline{p} > .19$, $\underline{MSE} = 113.78$; P/A x Duration, $\underline{F} < 1$; P/A x Lag, $\underline{F} < 1$; Duration x Lag, $\underline{F}(2, 46) = 2.89$, $\underline{p} > .06$, $\underline{MSE} = 113.78$; P/A x Duration x Lag, $\underline{F} < 1$.

Eccentric. Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 91.1; 600 ms duration, 91.1. The results from all lags were reanalysed in a 2 (first target: P/A) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. This analysis revealed a different pattern of results compared to the analysis that included lags 3-7. All three main effects were statistically significant: first target P/A, $\underline{F}(1, 23) = 10.09$, $\underline{p} < .005$, $\underline{MSE} = 83.82$; Duration, $\underline{F}(1, 23) = 55.11$, $\underline{p} < .001$, $\underline{MSE} = 271.51$; Lag, $\underline{F}(2, 46) = 3.82$, $\underline{p} < .03$, $\underline{MSE} = 128.06$. The only statistically significant interaction was the P/A x Lag interaction, $\underline{F}(2, 46) = 3.26$, $\underline{p} < .05$, $\underline{MSE} = 131.74$. All other interactions were not significant: P/A x Duration, $\underline{F}(1, 23) = 1.6$, $\underline{p} > .21$, $\underline{MSE} = 165.35$; Duration x Lag, $\underline{F}(2, 46) = 1.48$, $\underline{p} > .23$, $\underline{MSE} = 163.61$; P/A x Duration x Lag, $\underline{F} < 1$.

Combined and Eccentric combined. The results of the Present conditions were compared directly in a 2 (Location: Central or Eccentric) x 2 (Duration: 32 or

600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. As with the corresponding analysis that included only lags 3 and 7, two main effects were statistically significant: Location, F(1, 23) = 42.43, p < .001, MSE = 412.08; Duration, F(1, 23) = 47.91, p < .001, MSE = 175.72. The main effect of Lag was not significant, F(2, 46) = 15.67, p < .001, MSE = 163.75. Unlike the initial analysis, two interactions were statistically reliable: Location x Duration, F(1, 23) = 11.41, p < .003, MSE = 192.22; Location x Lag, F(2, 46) = 132.65, p < .01, MSE = 132.65. The remaining interactions were not significant: Duration x Lag, F(2, 46) = 1.81, p > .17, MSE = 109.75; Location x Duration x Lag, F(2, 46) = 1.49, p > .24, MSE = 23.

Discussion

The results of Experiment 6 are, for the most part similar to those observed in Experiment 5. As in Experiment 5, there was an effect of mask duration in the Central condition, but there was no difference between the first target Present and Absent conditions in terms mean level of performance nor was there an interaction between P/A and lag. And, as in Experiment 5, there was an effect of mask duration in the Eccentric condition, and again it was larger than that observed in the Central condition. However, unlike Experiment 5, in the Eccentric condition there was no interaction between first target P/A and lag. The interpretation of the results of the Central condition is the same as that discussed earlier: object substitution was observed (albeit a small effect), but there was no AB. The results of the Eccentric condition, however, warrant further consideration.

In Experiment 5, when the second target and mask were presented off-center, accuracy of identification depended on when the second target was presented relative to the first target and on the duration of the mask. That is to say, an AB was observed, but only when there was masking by object substitution (i.e., when the mask duration was long). One might argue that because there were no distractors presented simultaneously with the second target, that the conditions were not optimal for object substitution, despite the fact that masking was observed. Consequently, in Experiment 6, eight distractors were presented with the second target, which would improve the conditions under which object substitution might be observed. Object substitution masking was observed and, as one might predict, it was larger than that observed in Experiment 5. However, under these optimized conditions, and unlike Experiment 5, no AB was observed.

General Discussion

The objective of running Experiments 4-6 was to test the object substitution hypothesis presented in Chapter 3. Object substitution masking was observed in all conditions, although the effect was smaller when the mask trailed the second target and when the second target and mask were presented centrally. In contrast, there was little or no effect of first target presence and, with the exception of one condition, there was no interaction between first target presence and lag. That is to say, object substitution was observed, but on the whole there was no AB. The only exception was in Experiment 5, when the second target was presented off-center and was masked by a long duration mask. In this case, in addition to object substitution masking there appeared to be an AB. However, when this condition was re-run in Experiment 6, with conditions that should be more conducive to masking by object substitution (i.e., increasing the display set size), masking was observed, but there was no AB.

There is no clear theoretical explanation as to why this difference between Experiments 5 and 6 was observed. Indeed, any such explanation would be entirely ad hoc. At best, one can state that under some conditions high-level masking effects, such as masking by object substitution, can disrupt the processing of the second target. However, by and large, high-level masking effects do not mediate the masking of the second target during the AB. This is most certainly the case in the standard RSVP-AB paradigm where all items are presented in the same location. And this is clearly the case in the Central condition of Experiments 4-6 where masking by object substitution was observed, but no AB was observed. As for the results of the Eccentric condition, because of the observation of an AB in one condition in Experiment 5, and the absence of any AB in Experiments 4 and 6, the possibility still exists that the conditions were not optimal for high-level masking effects to disrupt the processing of the second target during the AB.

CHAPTER 6: FURTHER FAILURES OF THE OBJECT SUBSTITUTION HYPOTHESIS

In the experiments reported in the previous chapter, when the second target was presented off-center, it was presented at one of the cardinal locations with respect to the rest of the RSVP stream. This was true even when the set size of the second target display was nine items (Experiments 6). Even though masking was observed under these conditions, perhaps the spatial uncertainty was not optimal for masking by object substitution. Moreover, it is also possible that the set size used in Experiment 6 was not large enough to effectively distribute spatial attention to observe object substitution in its full force. This possibility, coupled with the discrepancy between the long mask duration Eccentric conditions in Experiments 4 and 5, warrants further exploration of the role of object substitution in the masking of unattended visual objects. The importance of this issue is underscored by the possibility of accepting the null hypothesis, namely, that masking by object substitution and other high-level masking effects do not cause the masking of the second target during the AB. Consequently, the issues of spatial uncertainty and set size were explored further in Experiments 7 and 8.

EXPERIMENT 7

In the Eccentric conditions of Experiment 6, when the second target was presented, eight distractors were also presented. The second target (and the mask) and the digits were arranged in a grid formation that was centered on the screen (see Figures 8 and 10). Although, the grid formation had nine possible locations, the second target was presented in only four of them. To be sure, the spatial uncertainty induced by choosing randomly between four locations, while effective in producing observable effects of mask duration, was certainly not the most powerful manipulation of spatial uncertainty. Indeed, a more powerful manipulation would have been to present the second target in any one of the nine possible grid locations. Alternatively, because all grid locations were filled on each trial subjects may become very efficient in detecting the location of the second target and mask within such a limited area. Consequently, simply increasing the number of possible second target locations may also not be the most powerful manipulation of spatial uncertainty.

Experiment 7 was similar to Experiment 6 in most respects except for the degree of spatial uncertainty. In Experiment 7, spatial uncertainty was increased by increasing the size of the second target displays from a 3 x 3 grid to a 5 x 5 grid. In addition, the second target appeared in any one of the possible 25 locations, including fixation. Finally, eight digits were also presented simultaneously with the second target and they were also presented in random locations in the larger grid formation. Thus, Experiment 7 represents a more powerful manipulation of the spatial distribution of attention by increasing the number of possible locations that the second target was presented, while maintaining the set size used in Experiment 6. There were two main predictions. First, the expectation was that the effect of mask duration should be larger than in previous experiments. Second, to the extent that masking by object substitution disrupts the processing of the second target while attention is devoted to the first, an AB should be observed under these improved conditions.

Method

Participants

Twenty-four undergraduates (18 female) from the University of Alberta subject pool participated for class credit (modal age = 18). Twenty of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure

The procedure for Experiment 7 was the same as Experiment 6, where the second target, the mask, and 8 digits were presented simultaneously at end of the RSVP stream. The main difference between this experiment and Experiment 6 was that the grid formation was enlarged to a 5 x 5 grid, where horizontal and vertical distance between the center of adjacent locations was 1°. In addition, the second target together with the mask and the 8 digits could occur in random positions within the grid formation at the end of the stream, including in the center position. All other aspects of the task remained unchanged from previous experiments. A sample display configuration is shown in Figure 11.

Insert Figure 11 about here

Design

There were two blocks of trials in Experiment 7. In one block of trials the first target was present and in the other the first target was absent. Within each block of trials the second target and 4-dot mask were presented in random locations on the screen, similar to the Eccentric conditions in the previous experiments, but with no constraint on the number of times the target was presented in each location. As with all the previous experiments, the duration of the 4-dots was either 32 ms or 600 ms. The second target was presented 32 times at each of the temporal lags (100, 300, or 700 ms) in each condition. The order of the dot-duration and temporal lag conditions was randomized within the Present and Absent blocks. The order of first target present or absent blocks was counterbalanced across subjects. This design resulted in 384 trials which were completed in a single 1-hour session.

Noise dots

Subjects began with 20 dots in both the Present and Absent conditions. The mean number of dots collapsed across all subjects were 9 and 10 for the Present and Absent conditions, respectively. The minimum and maximum values in the Present and Absent conditions were as follows: 0-30 and 0-20, respectively.

Results

As with the previous experiments, the presentation of the results of Experiment 7 is divided into sections. The first is the analysis of the data excluding lag 1; the second is the analysis of the data including all T1-T2 lags. Prior to these two sections will be a brief description of the main patterns in the data.

Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Figure 12. The most notable result shown in Figure 12 is the difference between Present and Absent conditions. Overall, mean percentage of correct identifications of the second target was slightly higher when the first target was absent than when it was present (Absent: 46.9; Present: 44.5). There was a large effect of mask duration, such that when the mask was of short duration accuracy was 53.1% and was 38.2% when the mask was of long duration. In addition, performance generally improved with lag, however, there was a clear interaction between P/A and Lag, such that the lag effect was observed in the Present, but not in the Absent condition. This interaction appeared to be driven by the low level of accuracy at lag 1 relative to the other lags.

Insert Figure 12 about here

Lags 3-7

Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 88.6; 600 ms, 90. The results in Figure 12 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. The only statistically significant effect was that of Duration, F(1, 23) = 109.79, p < .001, MSE = 110.73. All remaining effects were not statistically significant: first target P/A, F < 1; Lag, (1, 23) = 1.36, p > .25, MSE = 84.6; P/A x Duration, F(1, 23) = 2.17, p > .15, MSE = 81.34; P/A x Lag, F(1, 23) = 1.25, p > .27, MSE = 57.34; Duration x Lag, F(1, 23) = 3.72, p > .06, MSE = 84.54; P/A x Duration x Lag, F(1, 23) = 1.34, p > .26, MSE = 50.93;.

All lags

Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 86.8; 600 ms duration, 88.7. The results in Figure 12 were analysed in a 2 (first target: P/A) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. The inferential statistics supported the descriptive analysis of the results. Two main effects were statistically significant: Duration, F(1, 23) = 168.59, p < .001, MSE = 94.94; Lag, F(2, 46) = 22.55, p < .001, MSE = 59.04. There were also two statistically significant interactions: P/A x Lag, F(2, 46) = 13.24, p < .001, MSE = 73.99; P/A x Duration, F(1, 23) = 5.08, p < .04, MSE = 65.58. The main effect of P/A was not significant, F(1, 23) = 3.02, p > .09, MSE = 135.03, nor were the remaining interactions: Duration x Lag, F(2, 46) = 2.35, p > .10, MSE = 97.93; P/A x Duration x Lag, F < 1.

Discussion

In Experiment 7, the distribution of spatial attention was increased by increasing the spatial uncertainty about the location of the second target. The intention behind increasing the spatial uncertainty was to magnify object substitution masking. Indeed, the masking effect was large, on the order of 20%, but when the critical lags were compared (i.e., lags 3-7) there was no difference in the lag effect in the first target Present and Absent conditions. That is to say, masking by object substitution was observed, but there was no AB. Thus, the result of increasing spatial uncertainty by increasing the number of possible second target locations does not provide support for the object substitution hypothesis presented in Chapter 2.

One might argue, however, that increasing the number of possible second target locations was not the most effective approach to increasing the spatial distribution of attention. Indeed, Enns and Di Lollo (1997) demonstrated that when spatial uncertainty is controlled for, object substitution masking is stronger when there are more possible targets in the display and masking is observed at fixation (see also Di Lollo et al., 1999). Thus, with respect to object substitution masking, increasing the display set size appears to be a more effective manipulation of the distribution of spatial attention. Thus, the possibility still remains that the conditions for observing masking by object substitution have not been optimized. Experiment 8 addresses this possibility.

EXPERIMENT 8

In Experiment 8, the same number of second target locations was used as in Experiment 7, but the set size was increased to 18 (including the second target). That is to say, not only was there high spatial uncertainty in the display, but there were also a large number of distractor items in the display -- larger than previously used in 4-dot masking experiments (Di Lollo et al., 1999). Thus, if there are any conditions under which an AB was to be produced by high-level object substitution mechanisms, Experiment 8 presents the most likely conditions.

Method

Participants

Twenty-four undergraduates (20 female) from the University of Alberta subject pool participated for class credit (modal age = 18). Twenty-two of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure

The procedure was the same was in Experiment 7, except that in this experiment 17 digits were presented simultaneously with the second target and mask at the end of the stream.

Design

The design of this experiment was exactly the same as in Experiment 7.

Noise dots

Subjects began with 10 dots in both the Present and Absent conditions. The mean number of dots collapsed across all subjects were 4 and 6 for the

Present and Absent conditions, respectively. The minimum and maximum values for both the Present and Absent conditions were 0 and 20

Results

The results will be divided into sections, paralleling the presentation of the results of Experiment 7.

Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Figure 13. The trends in the data are virtually identical to those in Experiment 8. The only exception is that of the effect of P/A. As shown in Figure 13, accuracy of identification of the second target was higher in the Absent condition than in the Present condition (Absent: 49.6%; Present: 43.5%). Otherwise the results were identical to those of Experiment 7. There was a large effect of mask duration, such that when the mask was of short duration accuracy was 55.1% and was 37.9% when the mask was of long duration. In addition, performance generally improved with lag, however there was a clear interaction between P/A and Lag, such that the lag effect was observed in the Present, but not in the Absent condition. As with the results of Experiment 7, this interaction between P/A and Lag appeared to be driven by accuracy at lag 1.

Insert Figure 13 about here

Lags 3-7

Mean percentages of correct identifications of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 90; 600 ms, 88.5. The results in Figure 13 were analysed in a 2 (first target present or absent [P/A]) x 2 (mask duration: 32 or 600 ms) x 2 (lag: 300 or 700 ms) repeated measures ANOVA. The effect of removing the first lag from the analysis of the present experiment paralleled that observed in Experiment 8. There was a statistically significant effect of Duration, F(1, 23) = 109.79, p < .001 MSE = 110.73; but not of P/A, (1, 23) = 3.55, p > .07, MSE = 196.96, nor of Lag, F < 1. None of the interactions were statistically significant; P/A x Lag, F(1, 23) = 1.31, p > .26, MSE = 41.85; all other F's < 1.

All lags

Mean percentages of correct identification of the first target, collapsed across lags separately for the two mask duration conditions were as follows: 32 ms duration, 88.8; 600 ms duration, 87.7. The results in Figure 13 were analysed in a 2 (first target: P/A) x 2 (Duration: 32 or 600 ms) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. The inferential statistics supported the descriptive analysis of the results. All three main effects were significant beyond the .05 level: P/A, F(1, 23) = 13.14, p < .002, MSE = 202.04; Duration, F(1, 23) = 135.08, p < .001, MSE = 158.3; Lag, F(2, 46) = 9.18, p < .001, MSE = 82.27. There was a single reliable interaction: P/A x Lag, F(2, 46) = 5.56, p < .007, MSE = 70.66. All other interactions had F's < 1.

Discussion

Experiment 8 represented the strongest test of the object substitution account of the AB. Spatial uncertainty and set size were increased beyond those used in the previous experiments reported here and those of Enns and Di Lollo (1997; Di Lollo et al., 1999). Despite these methodological improvements, the results were same as Experiments 4-7. Indeed, the results of Experiment 8 were unequivocal: Masking by object substitution was observed, but there was no AB.

General Discussion

Based on the results presented in this chapter, and the results presented in Chapter 5, it appears that the object substitution account of the AB should be rejected. Indeed, the results support the conclusion that during the AB the representation of the second target is not vulnerable to masking by object substitution. Unfortunately, this conclusion is based on accepting the null hypothesis of no AB through lags 3-7. Consequently, before rejecting the object substitution account of the AB and accepting the null hypothesis, it is important to demonstrate that a) the AB can be produced within the context of the present paradigm and b) the concentration of the analysis on lags 3-7 be justified. These issues are addressed by the experiment presented in Chapter 7.

CHAPTER 7: REINSTATEMENT OF THE ATTENTIONAL BLINK

Based on the results of Experiments 4-8, it has been argued that object substitution does not disrupt the processing of the second target in an AB experiment. This argument has been based largely on the results of the data omitting lag 1, which was justified on the grounds of the work of Visser and his colleagues (Visser, et al., in press-a; Visser, et al., in press-b). Their work demonstrates that accuracy at lag 1 is independent of the magnitude of the AB. However, there are two possible shortcomings that undermine the conclusions drawn at present. Most notably, there has not been an unequivocal demonstration of the AB in the present paradigm. Similarly, there has not been a demonstration of the independence between lag-1 sparing and the AB within the context of the present experiments. On this analysis, one could argue that within the context of the present paradigm, which often involves the switching of spatial locations, that no AB would be observed under standard conditions where the second target is masked by a temporally-trailing spatially-superimposed pattern mask. Similarly, one could also argue that as a part of the validation of the overall paradigm, the independence between lag-1 sparing and the AB must be also be demonstrated. Experiment 9 was designed to address these issues.

EXPERIMENT 9

There were two goals for this experiment, 1) demonstrating that the AB can be observed in this paradigm and 2) demonstrating that the only difference between Central and Eccentric conditions is in terms of lag-1 sparing.

When one considers the first goal for this experiment, one must ask why no AB was observed with a 4-dot mask? There were three main design differences between those experiments where an AB was observed (Chapter 2) and those experiments where an AB was not observed (Chapters 5-7). These differences are 1) the temporal relationship between the second target and the mask (non-zero SOA vs. common-onset), 2) the spatial location of the second target and mask (i.e., central vs. eccentric), and 3) the figural properties of the mask (i.e., pattern vs. 4-dot mask). Experiment 4 demonstrated that the temporal relationship between the second target and the mask was not a factor in the failure in observing an AB. And previous research has demonstrated that the AB is observed when the second target and its mask are not presented in the same location as the first target or the rest of the RSVP stream (Duncan et al., 1994; Moore et al., 1996; Visser et al., in press-b). Thus the most likely candidate for why an AB was observed in Chapter 2 and not in Chapters 5-7 concerns differences between the figural properties of the digit mask used in Chapter 2 and the 4-dot mask used in Chapters 5-7.

When considering the second goal of the experiment, one must compare the AB that is observed when the second target is presented in the same location as the first target (i.e., where lag-1 sparing would be observed) to the AB that is observed when the second target is presented in a different location. Visser et al. (in press-b) demonstrated that the only difference between the conditions where the first and second targets were presented in the same location and the conditions where two targets were not presented in the same location was in second target identification accuracy at lag 1. Namely, when the targets were presented in the same location, performance at lag 1 was high, similar to that at lag 7. In contrast, when the two targets were presented in different locations, performance at lag 1 was the lowest across all lags. In contrast, second target identification accuracy was at the same level at lags 3 and 7, regardless of location. In other words, the only difference between the same-location and different-location conditions was in the level of performance at lag 1. Further, Visser et al. (in press-a) have also shown that across many studies of the AB, the magnitude of lag-1 sparing is independent of the magnitude of the AB across the subsequent lags.

To fulfill the two goals of the present study, Experiment 9 used the same visual display as Experiment 4 with the exception that the 4-dot mask was changed to a digit (i.e., a pattern mask). Thus, the only difference between the mask used in this experiment and that used in the previous experiment was the difference in figural properties: the digit mask had contours that spatially overlapped the second target, whereas the 4-dot mask of the previous experiment did not. As with the previous experiment, the second target was presented in the same location as the rest of the stream or it was presented above, below, to the left, or to the right of the rest of the stream. There were two predictions. First, because of the change in the mask, an AB would be observed. Second, if the AB is independent of lag-1 sparing, then the AB across lags 3 and 7 would be observed regardless of where the second target was presented. Moreover, the only difference between the conditions when the second target was presented centrally compared to when it was presented eccentrically would be in terms of lag-1 sparing.

Method

Participants

Twenty-four undergraduates (15 female) from the University of Alberta subject pool participated for class credit (modal age = 19). Nineteen of the participants were right handed and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure

The procedure was the same as Experiment 4 in most respects: the second target was presented without distractors and, in the eccentric condition, the second target was presented only at the 4 cardinal positions. The only difference was in the nature of the mask. In the present experiment the second target was pattern masked by a temporally-trailing, spatially-superimposed digit (i.e., as in Chapter 2). The timing between the second target and the digit mask was the same as between any two items in the rest of the RSVP stream. Namely, the second target was presented for 32 ms, followed by a blank ISI of 68 ms, followed by the 32 ms presentation of the digit mask.

Design

The design of this experiment was exactly the same as in Experiment 4. In different blocks of trials, the first target was Present or Absent, the second target was Central or Eccentric, and the temporal lag was either 100, 300, or 700 ms. The second target was presented 32 times at each of the temporal lags. Counterbalancing was carried out as described in the Method of Experiment 4.

Noise dots

The starting number of dots for each block was 20. The mean number of dots in each block collapsed across all subjects were as follows: Present-Central, 16; Present-Eccentric, 12; Absent-Central, 20; Absent-Eccentric, 16. The minimum and maximum number of dots in each block were as follows: Present-Central, 0-30; Present-Eccentric, 0-20; Absent-Central, 0-40; Absent-Eccentric, 0-30.

Results

The results of Experiment 9 were analysed in the same fashion as the results of Experiments 4-6, where there were both Central and Eccentric conditions. Namely, the results are divided in two sections: the first includes lags 3 and 7 only and the second includes all lags. Within each section, the results are analysed separately for each location condition and then the first target present conditions are compared directly.

Lags 3-7

Central. Mean percentage of correct identifications of the first target, collapsed across lags was 88.7. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel A of Figure 14. There were two main results. First, overall accuracy of identification of the second target was higher in the Absent condition than in the Present condition. Second, there was a clear interaction between first target P/A and lag. In the Absent condition, performance did not change as a function of lag (mean across lags = 54%). In the Present condition, however, accuracy changed as function of lag: accuracy was near 32% at lag 3, but was near 55% at lag 7.

Insert Figure 14 about here

The results in Panel A of Figure 14 were analysed in a 2 (first target: P/A) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. Both the main effect of P/A and Lag were highly significant: first target P/A, $F(1, 23) = 15.12$, $p < .001$, $MSE = 110.76$; Lag, $F(1, 23) = 28.58$, $p < .001$, $MSE = 94.64$. The P/A x Lag interaction was also significant, $F(1, 23) = 28.23$, $p < .001$, $MSE = 103.01$.

Eccentric. Mean percentage of correct identifications of the first target, collapsed across lags was 89.3. Mean percentages of correct identifications of the second target as a function of lag, averaged over all subjects, are shown in Panel B of Figure 14. Unlike the results of the Central condition, there was no overall difference between accuracy in the Present and Absent conditions (45% and 46.9%, respectively). However there was the clear interaction between first target

P/A and lag. In the Absent condition performance did not change as a function of lag (mean across lags = 46.8%). In the Present condition, however, accuracy was lowest at lag 3 (37.5%) and was highest at lag 7 (52.5%).

The results in Panel B of Figure 14 were analysed in a 2 (first target: P/A) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. The main effect of first target P/A was not significant ($\underline{F} < 1$). However, the main effect of Lag was statistically significant, $\underline{F}(1, 23) = 23.44$, $\underline{p} < .001$, $\underline{MSE} = 89.39$; as was the P/A x Lag interaction, $\underline{F}(1, 23) = 7.31$, $\underline{p} < .02$, $\underline{MSE} = 106.44$.

Combined and Eccentric combined. Visual inspection of the Present conditions (Figure 14, filled symbols) suggests that there was no difference in overall level of performance nor in the lag effect in the two conditions.

The Central and Eccentric conditions were compared directly in a 2 (Location: Central or Eccentric) x 2 (Lag: 300 or 700 ms) repeated measures ANOVA. There was a significant main effect of Lag, $\underline{F}(1, 23) = 54.63$, $\underline{p} < .001$, $\underline{MSE} = 147.62$. However, the main effect of Location was not significant ($\underline{F} < 1$). Similarly, the Location x Lag interaction was not significant, $\underline{F}(1, 23) = 2.27$, $\underline{p} > .14$, $\underline{MSE} = 114.25$.

All lags

Central. Mean percentage of correct identifications of the first target, collapsed across lags was 87.9. The results were reanalysed including all lags, in a 2 (first target: P/A) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA.

As with the initial analysis , both the main effect of P/A and Lag were statistically significant: first target P/A, F(1, 23) = 14.9, p < .001, MSE = 65.57; Lag, F(2, 46) = 19.18, p < .001, MSE = 84.77. Similarly, the P/A x Lag interaction was also significant, F(2, 46) = 15.09, p < .001, MSE = 119.95.

Eccentric. Mean percentage of correct identifications of the first target, collapsed across lags was 87.8. The results in Panel B of Figure 14 were reanalysed in a 2 (first target: P/A) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. With one exception, the reanalysis of the data paralleled the analysis that included lags 3-7. The exception was that including lag-1 in the analysis resulted in a significant effect of first target P/A, F(1, 23) = 9.51, p < .006, MSE = 135.51. As before there was a significant effect of Lag, F(2, 46) = 9.94, p < .001, MSE = 114.41; and a significant P/A x Lag interaction, F(2, 46) = 10.33, p < .001, MSE = 96.09.

Combined and Eccentric combined. When all lags are considered, the graphical evidence shown in Panels A and B of Figure 14 reveals an interaction between the two Present conditions (filled squares). Namely, in the Central condition second target accuracy changes nonmonotonically as a function of lag, whereas in the Eccentric condition accuracy changes monotonically as a function of lag. These data were analysed in a 2 (Location: Central or Eccentric) x 3 (Lag: 100, 300, or 700 ms) repeated measures ANOVA. As with the initial analysis, there was a significant effect of Lag, F(2, 46) = 32.69, p < .001, MSE = 123.37. However, unlike the analysis that included lags 3-7, the reanalysis revealed a significant main effect of Location, F(1, 23) = 16.94, $p < .001$, MSE = 87.47, and a significant Location x Lag interaction, F(2, 46) = 10.17, $p < .001$, MSE = 131.31.

Discussion

There were two notable results of this experiment. First, regardless of the location of the second target relative to the first, an AB was observed. Second, the only difference between the Central and Eccentric conditions was the magnitude of lag-1 sparing. In the Central condition, the mean percentage of correct responses at lag 1 was more than 20% better than at lag 3. In the Eccentric condition, on the other hand, the mean percentage of correct responses at lag 1 was 2% lower than at lag 3. Otherwise the two performance functions were virtually identical. Both results warrant further discussion and each will be addressed in the following paragraphs, in turn.

The main difference between Experiment 9 and Experiments 4-8 was in the type of mask used. In the latter, the mask was four dots that surrounded, but did not overlap, the second target. In the former, the mask was the same the interruption mask used in Experiments 1 and 2 of Chapter 2. With this type of mask a large AB deficit was observed. This result provides a validation of the present paradigm, i.e., it can produce a robust AB. More importantly, it speaks of a fundamental difference between an object substitution mask and a backward pattern mask. This difference is one of the fundamental issues that is germane to the purpose of the present series of experiments. Consequently, further treatment of this issue will be left for the General Discussion.

The finding that the only difference between the Central and Eccentric conditions was in the magnitude of lag-1 sparing replicates the results of Visser and colleagues (in press-b). This replication supports the notion that the mechanisms that mediate the AB and the mechanisms that mediate lag-1 sparing are independent (see also Visser et al., in press-a). More importantly for the present results, however, is that this replication justifies basing conclusions only on the analyses omitting lag 1.

General Discussion

In summary, two important implications emerged from the empirical work reported in this chapter. First, it demonstrated that the AB can be observed in this paradigm. Second, it demonstrated that lag-1 sparing is not related to the AB. By fulfilling these goals, this experiment validates the conclusion put forth at the end of Chapter 6. Namely, the object substitution account of the AB should be rejected, i.e., during the AB the representation of the second target is not vulnerable to masking by object substitution.

CHAPTER 8: GENERAL DISCUSSION

The results presented in Chapter 2 demonstrated unequivocally that masking of the second target was a necessary condition for observing the AB deficit. More specifically, the second target must be masked by a temporally-trailing, spatially-superimposed stimulus. Based on the pattern of intrusion errors observed during the AB (Chun, 1997; Isaak et al., in press) and the evidence supporting semantic processing during the AB (Luck, et al., 1996; Maki, Frigen, & Paulson, 1997; Shapiro, Driver, Ward, & Sorensen, 1997a; Vogel, et al., 1998), the mechanism involved was assumed to be one of object substitution: a high-level form of masking that was independent of contour overlap and proximity and viewing conditions (Di Lollo et al., 1999; Enns & Di Lollo, 1997). On this premise, the working hypothesis was that the representation of a temporally-trailing pattern mask substituted that of unattended objects. The experiments presented in Chapters 5-7 were designed to test explicitly the object substitution hypothesis.

The object substitution hypothesis made explicit predictions regarding the nature of the masking that results in the AB: when an object substitution mask is used on the second target, an AB should be observed. Experiments 4-8 tested this prediction. In these experiments, the second target was masked by a four-dot mask, which has been demonstrated to be an effective object substitution mask. Indeed, the mask was effective particularly when attention was distributed over space due to manipulations of spatial uncertainty (Experiments 4 and 5) and/or set size (Experiments 6-8). Nevertheless, no AB was observed. This was true both when the mask had a common-onset with the second target (Experiments 5-8) and when it did not (Experiment 4). Thus, onset-locked transient mechanisms can be ruled out as a factor in the production of the AB. In contrast, when the mask was changed to a digit that followed the second target, a robust AB was observed (Experiment 9). According to the object-substitution hypothesis, an AB should have been observed in all conditions of Experiments 4-8. Thus, object substitution cannot be the masking mechanism that produces the AB, and therefore it must be rejected as a component in the theories that use it as an explanation of masking during the AB.

Before bringing the results of this thesis to bear on current models of the AB, it is imperative to address the issue of basing the conclusions on lags 3-7, while excluding lag 1. As discussed previously, this approach was based on the evidence that performance at lag 1 and the magnitude of the AB are not related. Using this approach, it has been argued that despite observing strong object substitution masking, no AB was observed. Consequently, the object substitution hypothesis must be rejected. However, it must be noted that consideration lag 1 does not change this conclusion, in fact it strengthens the conclusion that object substitution does not mediate masking of the second target during the AB. To be clear, consider Figure 13 (filled symbols). In both the 32 ms and 600 ms duration conditions accuracy at lag 1 was low and improved monotonically as lag increased. The majority of the improvement occurred between lags 1 and 3, whereas there is virtually no difference in accuracy between lags 3 and 7. On this pattern of results, one might argue that an AB was actually observed, but that it was restricted to lag 1. Thus, contrary to what has been argued here, one would argue that the results when lag 1 is included support the object substitution hypothesis. However, further consideration of this alternative explanation proves it to be not tenable. Consider again Figure 13 (but also Figures 10 and 12). If the alternative explanation is adopted, one would conclude that an AB was observed in both the 32 ms and 600 ms duration conditions. In the 32 ms condition the target and mask had simultaneous onsets and off-sets. It has been demonstrated that under conditions of simultaneous onsets and off-sets, masking by objects substitution masking is not observed (Di Lollo et al., 1999; Enns & Di Lollo, 1997). This is problematic for the alternative explanation that claims there is an AB when one includes lag 1 data because it would predict that because no object substitution should be observed, no AB should be observed. This alternative further runs afoul when one considers the additivity between the lag effect (both including and excluding lag 1) and masking by object substitution. This additivity strongly suggests the mechanisms that underlie the lag effect (at lag 1 and lags 3-7) are independent of those that underlie masking by object substitution. Thus, even if lag 1 is included in the data, the object substitution hypothesis must be rejected.

Accounts of masking during the AB deficit

Besides the object substitution hypothesis, there are six main accounts of the AB deficit in the literature. Three of these models were discussed in Chapter 2. These models are the two-stage model (Chun & Potter, 1995), the interference model (referred to as the competition model in Chapter 2; Shapiro et al., 1994), and the dwell-time model (Duncan et al., 1994; Ward et al., 1996). In addition, three models have been presented since the original report of the findings of Chapter 2 (i.e., Giesbrecht & Di Lollo, 1996). These models are as follows: the short-term consolidation model (Jolicoeur, 1998); the unified model (Shapiro et al., 1997); and the hybrid model (Vogel et al., 1998). In broad terms, there is a close resemblance in how each of the models account for the AB deficit: The AB is the result of restricted resources or limited-capacity processing that prevent the second target from being encoded or retrieved for report. The models also are also similar in that they make claims regarding the fate of the second target when it can not be encoded into a more durable form. In the following paragraphs, each of the models will be described briefly, with particular emphasis placed on how they account for masking of the second target during the AB and how their accounts explain the results of Experiments 4-9[4].

As described earlier, the two-stage model (Chun & Potter, 1995) divides visual processing into two sequential stages. Potential targets are detected in Stage 1 and then passed on to a limited-capacity second stage (i.e., Stage 2), where items are processed more completely and then encoded into a more durable form for report. Items only gain access to Stage 2 if Stage 2 is not already busy processing a previous target. If Stage 2 is busy, potential targets detected in Stage 1 remain in Stage 1. What is most important for the present purpose is that targets delayed in

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[4] The models are only related to Experiments 4-9 for two reasons. First, three of the models (i.e., the two-stage, interference, and dwell-time models) have already been discussed in terms of the results of Experiments 1-3; therefore, it would be redundant to do it again. Second, the other three models (i.e., the short-term consolidation, unified, and hybrid models) have all been published since the report of Experiments 1-3; therefore, each has made assumptions to account for the results of Experiments 1-3.

Stage 1 remain vulnerable to decay and/or interference from temporally-trailing spatially-superimposed stimuli.

Chun and Potter (1995) proposed two sources of masking that interfere with the Stage 1 representation of the second target: erasure and overwriting. Labeling the one source of interference as erasure implies that the mechanisms underlying erasure are similar to that proposed by the object substitution hypothesis: namely, while delayed in Stage 1, the representation of the second target is substituted by the representation of a temporally trailing mask. Overwriting, on the other hand, implies that the representations of the second target and the mask are spatially overlapped. On this analysis, erasure can not account for the difference between a backward pattern mask and the 4-dot mask -- both should produce an AB. In contrast, overwriting can account for the lack of an AB in the present experiments. Consider the 4-dot mask experiments, where the mask did not spatially overlap the second target. In this case, the representation of the second target is not degraded by the mask because they do not have common contours. Consequently, factors relating to decay notwithstanding, the representation that is available to Stage 2 is a combination of the second target and the mask, much like the simultaneous conditions of Experiments 1 and 2. On this account, an AB should not be observed when a 4-dot masking is used.

As discussed in Chapter 2 the interference model (Shapiro et al., 1994) is based on a notion of interference among objects in visual short term memory (VSTM). To enter VSTM, items must match pre-set templates corresponding to the first and second targets. If a potential target gains access to VSTM, the item immediately following this target also gains entry into VSTM because of its close temporal contiguity to the immediately preceding item. Thus, in the typical case only four items gain access to VSTM: because of their match with the templates the first and second targets gain access, but their respective masks also gain access because of their close temporal contiguity with the targets. These items are assigned weights on their match with the corresponding templates. Attentional resources are allocated based on this weight and the item's order of entry into VSTM. Consequently, the first target is assigned the largest amount of resources and the item following the second target the least. For the interference model, the AB is explained as a condition of restricted resources available to process the second target at short lags.

The interference model provides a straight-forward explanation of the failure to observe an AB in Experiments 4 and 5, where the second target was presented alone in the visual field. In this case, because the second target and mask were presented simultaneously, they would most likely be admitted into VSTM as a single object. Thus, there would only three items in VSTM, the first target and its mask, and the combination of the second target and the 4-dot mask. Consequently, VSTM would not be at its full capacity. Moreover, the similarity between the second target and the first target would be reduced because of the mask presented with the second target: One representation includes 4-dots (i.e., the second target) and the other does not. Consequently, no AB would be observed. However, the interference model runs into difficulty accounting for the lack on an AB in Experiments 6-8, where the second target was present with distractors. Indeed, the set sizes of 9 and 18 used in these experiments would surely overload the limited capacity of VSTM. Consequently, a large AB should have been observed under these conditions. But this was not the case.

Another account of the AB described in Chapter 2, is based on a concept of attentional dwell time (Duncan et al., 1994; Ward et al., 1996). These authors suggest that attention remains concentrated on the first target for several hundred milliseconds before it can be reoriented to the second target. During this dwell time, the second target cannot be processed adequately, and its identification suffers correspondingly. This account shares broad similarities with that of Chun and Potter (1995), in that processing of the second target is said to suffer while the system is busy with the first. As mentioned in Chapter 2, this account is incomplete. There are no assumptions regarding the mechanisms of masking of the second target -- processing of the second target is merely less efficient because attention is devoted to the first target.

More recently, Jolicoeur (1998) has presented a dual-task interference account of the AB that is strikingly similar to the two-stage model (Chun & Potter, 1995). In this model, visual processing is divided into discrete sequential stages of sensory encoding, perceptual encoding, memory encoding, and memory retrieval. For a target object to be reported it must go through all stages of processing. In this model, each stage places different requirements on the system. The sensory/perceptual encoding stage is unlimited in capacity, thus, at this stage multiple targets can be processed in parallel. In contrast, the memory encoding stage requires access to processing mechanisms that are of limited bandwidth, thus, at this stage, multiple targets can not be encoded into memory in parallel. Moreover, the mechanisms that are required for memory encoding are also required for selecting responses in speeded tasks (e.g., Pashler, 1994). This model, accounts for the AB in the following manner. When T2 is presented very soon after T1, the limited bandwidth mechanisms required for encoding T2 into memory are busy encoding T1 into memory. As in the two-stage model, while the first target is being encoded, the representation of the second target is vulnerable to masking.

In the short term consolidation model, masking takes place at the perceptual encoding stage. At this stage, semantic representations of the targets are created and are subject to decay. The role of the mask is clear: a backward mask degrades the representation of the second target (Jolicoeur, in press). The role prescribed to the mask allows for the short-term consolidation model to account for the results presented in Chapter 2. Namely, if the second target is not masked or masked by integration, visible persistence "bridges the gap" between the time of presentation of the second target and the time when the memory encoding stage is free to encode the second target. Thus, no AB is observed. When the second target is backward masked, the representation is degraded by the mask and this is observed only when the representation of the second target can not be encoded into memory immediately after its presentation. What is not clear in this model is a description of the precise mechanisms that mediate masking of the second target (i.e., object substitution or otherwise). Thus, this model must be considered incomplete with regard to the mechanisms that underlie masking during the AB.

As its name implies, the unified model (Shapiro, et al., 1997b) is an attempt to reconcile the accounts of the AB. In doing so, it draws on the similarities and strengths of the models described so far. This model is based on the following three tenets. First, when the first target is masked, more attention is required to sufficiently processing the target for report. Second, as a consequence of the resources devoted to the first target, the second target can not be completely processed for accurate report. This leaves the second target susceptible to decay and/or masking by object substitution. As the first target identity is resolved and reaches awareness, the susceptibility of the second target to masking declines, resulting in the typical AB curve. Finally, if the information processing system is further taxed (e.g., requiring a speed response to the first target), there will be a direct impact on second target accuracy.

In contrast to the short-term consolidation model, the unified model makes a clear claim regarding the mechanism involved in masking during the AB: if the second target can not be processed immediately, its representation is vulnerable to masking by object substitution. Thus, based on the unified model, the hypothesis is the same as with the object substitution account, namely, that the AB should have been observed in the present experiments. And, as was the case for the object substitution hypothesis, this prediction by the unified model has been shown to be incorrect.

The final model to be considered, the hybrid model (Vogel et al., 1998), is very similar to that of the unified account. That is to say, the hybrid model incorporates many of the strengths its predecessors, particularly the two-stage and interference models. According to this model, all RSVP items are initially stored in conceptual short term memory (CSTM). Items at this level of representation are fully identified, but not available for report. The notion of CSTM is very similar to Jolicoeur's perceptual encoding stage and the intermediate buffer in the revised two-stage model. For an item to be reported, it must be transferred from CSTM to visual working memory (VWM). This transfer is mediated by attentional templates, similar to that suggested in the visual search literature (e.g., Duncan & Humphreys, 1989). The AB is observed when attention is engaged in transferring the first target from CSTM to VWM. In this case, the second target representation is delayed in CSTM and is susceptible decay and to interference from other stream items. In this way, the AB is the result of the inability to retrieve the representation of the second target because it was not encoded into VWM, even though it was accurately generated at low-level perceptual stages.

As with the unified model of the AB, the hybrid model makes a clear claim regarding the source of interference CSTM. Indeed, the claim is the same as the unified model: while attention is engaged with the first target, the representation of the second target decays and is vulnerable to replacement (i.e., object substitution). In turn, the hybrid model predicts that the AB should be observed when the second target is masked by a 4-dot mask. Unfortunately, the fate of this masking account is the same as the others described here -- it must be rejected.

In summary, in addition to the object substitution hypothesis generated from the revised two-stage model, two other models of the AB incorporate masking by object substitution (i.e., the unified and hybrid models). Each of these models account for the AB is based on the premise that while attention is engaged with the first target the representation of the second target is vulnerable to masking by object substitution. Based on the results of this thesis, however, the masking account generated by each of these models must be rejected. Similarly, the two-stage model assumes that masking is caused by erasure and/or overwriting. Erasure equates with object substitution and therefore it must be rejected. Masking by overwriting, on the other hand, can account for the lack of an AB observed in Experiments 4-8. The short-term consolidation model, while prescribing a role for masking of the second target, fails to define the mechanisms that underlie masking. Similarly, although the interference model is strained when accounting for the lack of an AB in Experiments 6-8, this model does not make specific claims regarding the mechanisms that underlie masking of the second target. The must be said for the dwell-time model.

Low-level masking effects during the AB

The rejection of the object substitution hypothesis begs the question: If object substitution mechanisms do not underlie masking of the second target during the AB, then what mechanisms are involved? The immediate alternative is that the masking that produces the AB is mediated largely by low-level masking mechanisms. This is not to say that other mechanisms are not involved. Indeed, decay of the target representation is likely to be involved. However, under typical conditions, passive decay of the visual representation is not sufficient to observe the AB (Chapter 2, but see Enns, Visser, Kawahara, & Di Lollo, in press for conditions where decay may be sufficient). Importantly, the proposal here is that low-level masking mechanisms are the main mechanisms that underlie masking of the second target during the AB.

In the corpus of the published AB literature, every experiment where an AB was observed, the second target was masked by a temporally-trailing, spatially-superimposed pattern. Backward masks of this sort have a distinct low-level component: The target and mask share similar contours. Contour similarity is one of the major variables in low-level masking effects. The more similar the contour between the target and the mask, the stronger the masking effect (for comprehensive reviews see Breitmeyer, 1984; Scheerer, 1973)[5]. Thus, if low-level masking effects mediate masking of the second target during the AB, then there should be a relationship between the severity of the AB and second-target mask similarity. The present experiments allow for examination of the relationship between contour similarity and AB magnitude.

In the present work, three different types of stimuli were used to backward mask the second target: a digit (Experiments 1, 2, and 9), a patch of noise dots (Experiment 3), and a 4-dot mask (Experiment 4-8). The only difference between these masks was in the structural similarity between the target and the mask. For the sake of comparison, AB magnitude was calculated for the Central conditions of Experiments 5 (4-dot mask) and 9 (digit mask) and Experiment 3 (noise-dot mask). As a rough estimate, AB magnitude was calculated by subtracting overall mean accuracy at lag 3 from the mean accuracy at lag 7 (Visser, et al., in press-a; but see Jolicoeur, 1998; Shapiro, et al., 1994 for alternative methods of calculating AB magnitude); the results of this simple analysis are shown in Figure 15. The only difference between the conditions shown in Figure 15 was in the structural relationship between the target and the mask: on the left is the 4-dot mask, which has the smallest amount of contiguous contour; on the right is the digit, which has the largest amount of contiguous contour; and in the middle is the noise-dot mask. It is clear that AB magnitude declines with the apparent amount of common contour. This result parallels findings in the masking literature that illustrate that masking magnitude is related to contour overlap (e.g., Schiller, 1966; for reviews see Breitmeyer, 1984; Scheerer, 1973). More importantly, it supports the notion that masking of the second target during the AB is subserved by low-level mechanisms.

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[5] It must be noted that this relationship excludes the extreme possibility of a perfect correspondence between the contours of the target and the mask, in which case masking would not be observed.

Insert Figure 15 about here

To a first approximation, appealing to low-level masking is inconsistent with many of the findings in the literature. Indeed, it has been argued that the low-level visual representation of the second target is destroyed by the mask, yet there are several published observations that an unreported second target is processed to a semantic level (e.g., Luck & Vogel, 1996; Maki et al., 1997; Shapiro et al., 1997; Vogel et al., 1998). Beyond a first approximation, however, simply because the early representation is masked at a low-level, does not mean that the item can not be processed beyond an low-level. Consider that in the present experiments, when a delayed mask was used, each item (targets and distractors) was clearly suprathreshold -- subjectively, there was a constant stream of stimuli with no "hiccups" as might be expected if some stimuli were not suprathreshold. To be sure, each item enters into the visual system and therefore can be processed to some extent. Moreover, the SOA between the target and the mask was 100 ms, enough time to process the category of an item, otherwise the first target could not be picked out from the stream (Chun & Potter, 1995). Therefore, despite the fact that the early representation is masked by low-level processes, it is still possible that processing can proceed beyond an low-level. Formal demonstrations of this possibility come from the literature on masked priming and perception without awareness where subthreshold stimuli have been shown to influence behaviour (Cheesman & Merikle, 1986; Marcel, 1983a; Marcel, 1983b; see also Chapter 2).

Implications for models of the AB

Identifying low-level masking effects as underlying masking of the second target may seem problematic for accounts of the AB, particularly those that implicate object substitution. However, the results of the present thesis do not completely undermine all the tenets of each of the models. To be sure, the present results merely require that one assumption of each of the models be changed (or added in the case of the short-term consolidation model and the dwell-time model):

while processing capacity is devoted to the first target, the low-level visual representation of the second target is vulnerable to masking via low-level masking mechanisms. Of the extant models, the two-stage and short-term consolidation models would have to be changed the least. With regard to the two-stage model, seemingly low-level mechanism of overwriting was initially implicated, thus no changes would have to be made. With regard to the short-term consolidation model, the early representation of the second target is identified as being degraded by the mask, the addition would come in terms of the precise mechanisms that underlie the degradation. Otherwise the models can remain unchanged.

It is also noteworthy that although the specifics of the models differ, without exception, each explains the AB as a failure of high-level cognitive processes to encode the second target. This issue is not in dispute. However, Experiments 1-3 illustrated that for this high-level failure to be observed, particular conditions must be met: the second target must be masked by a trailing pattern. The implicit assumption was that because the AB reflected a high-level cognitive failure, the masking effect must also be mediated by high-level mechanisms. This assumption had intuitive appeal and was supported by converging lines of evidence showing that an unattended second target was processed to a semantic level (Maki et al., 1997; Shapiro et al., 1997; Vogel et al., 1998). Consequently, this assumption was embodied in the object substitution hypothesis incorporated into the revised two-stage model (Chapter 3; (Giesbrecht & Di Lollo, 1998). The appeal of this assumption was not lost on others. Indeed, two of the models of the AB that have been published since the initial presentation of the object substitution hypothesis have embodied the same assumption (Shapiro et al., 1997; Vogel et al., 1998).

One of the by-products of the assumption that high-level processing must be disrupted by a similarly high-level mechanism has been to make explanations of the AB more complicated. For example, the revised two-stage model added an intermediate buffer between Stages 1 and 2. The increased complexity was needed, in part, to reconcile apparent high-level cause of the AB -- disruption of postperceptual processing -- with the effect of masking in the AB (see also Shapiro et al., 1997; Vogel et al., 1998). Experiments 4-9, however, demonstrate that the logic that a high-level phenomenon needs to be disrupted by a high-level mask is incorrect. Indeed, Experiments 4-9 show that this is not the case: during the AB, processing is not disrupted by a high-level mask. The simpler, and equally plausible, alternative is that in order for this high-level phenomenon to be observed, early visual representations must be disrupted by a low-level mask.

Future directions

Adopting the low-level masking hypothesis allows one to use what is known about low-level visual processes to make distinctive predictions. Perhaps the most distinctive prediction is the effect of adapting luminance on the AB. It is well-established that the low-level visual response is very different under dark-adapted (scotopic) and light-adapted (photopic) viewing conditions. Under photopic viewing conditions the retinal response is faster compared to the response under scotopic viewing conditions. Moreover, the response under photopic viewing conditions is biphasic: An initial positive phase is followed by an negative phase. In contrast, under scotopic conditions the retinal response shows only a positive phase (Di Lollo & Bischof, 1995). The positive phase in both conditions is thought to represent excitatory activity triggered by the onset of a stimulus and the temporal extent of the positive phase is thought to be an index of visible persistence (Di Lollo & Bischof, 1995). The negative phase is thought to represent inhibitory activity triggered by the offset of a stimulus. This inhibitory activity is thought to be responsible for suppressing persistence beyond stimulus offset. The suppression of persistence is thought to occur early in visual processing (i.e., no later than V1) and is thought to mediate low-level masking effects (Breitmeyer, 1984). On this analysis, the low-level masking hypothesis would predict the AB should be observed only under photopic viewing conditions, under scotopic conditions no masking would be observed.

Recently, my colleagues and I tested this prediction (Giesbrecht, Bischof, & Kingstone, 1998). In this experiment, subjects were tested in an experiment very similar to those reported in Chapter 2, where the task was to identify two letters in an RSVP stream of digits and the second target was always masked by a single digit. The same subjects were tested under photopic and scotopic viewing conditions. Under the typical task parameters (i.e., two targets and a 100 ms SOA between all RSVP items), an AB was observed under photopic conditions. In contrast, there was no AB under scotopic viewing conditions. This result is exactly what would be predicted if low-level masking effects mediate masking of the second target during the AB. However, this result contrasts sharply with the object substitution hypothesis, which predicts that the AB should be observed under both photopic and scotopic viewing conditions. Overall then, there appears to be suggestive evidence that low-level visual processes mediate masking of the second target during the AB.

Beyond the attentional blink: Concluding remarks

The AB is commonly held to represent the time course of attentional and memory encoding processes that are required for one to be aware of an object. However, the present work demonstrates that to understand these processes we must also understand the conditions under which these processes can be observed. The importance of this issue applies not only to studies of the AB, but for studies of attention in general. Indeed, Allport (1989) offers a more precise formulation of the issue at hand: "What is the overall *purpose* (or what are the overall *purposes*) of attention, and what are the determining and enabling *constraints* on attentional processes?" (p. 631). The answer to this question is at the core of attentional research.

Within the context provided by Allport (1989), this thesis has addressed the *constraints* on attentional processes. More specifically, the empirical work demonstrated a particular limitation of attentional processes. Consider that there are two conditions required for observing the AB. Theoretical arguments notwithstanding, the first is that attentional mechanisms must be engaged on the first target. The second is that the representation of the second target must be masked by low-level visual processes. The former condition has been well demonstrated and is incorporated into each of the models of the AB. To be sure, the AB is commonly held to represent the consequences of attention through the failure of encoding or retrieving the second target. However, as demonstrated by the present work, these consequences can only be observed when the conditions at early levels of the visual system are ripe -- namely, when bottom-up support for attentional processes is removed within the early stages of the visual system.

When cast in this light, the AB represents one of a larger class of phenomena that represent a variety of interactions between attention and perception. This class of phenomena contains examples from both neurologically intact and impaired populations. For example, with induced change blindness, when neurologically healthy individuals distribute their attention over the whole visual field, global changes may remain unnoticed for long periods of time (Rensink et al., 1997). This phenomenon implicates a very similar interaction between attention and perception as the one discussed in this thesis. In contrast, consider visual neglect, a neurological syndrome that often follows unilateral brain damage from a stroke (for a recent review see Rafal, 1998). In this syndrome, patients have intact visual systems (i.e., at least up to V1), yet they are unaware of locations or objects in the contralesional visual field (e.g., Posner, Walker, Friedrich, & Rafal, 1984; Posner, Walker, Friedrich, & Rafal, 1987; Rafal, 1998).

Thus, to answer the second part of Allport's question, one constraint on attentional processes is how they interact with perception. Unfortunately, the answer to the first part of the question -- what is the purpose of attention -- remains more elusive. However, by investigating the interactions between attention and perception -- and their underlying brain mechanisms -- science can work towards identifying the purpose of attention and how it is related to coherent behaviour and consciousness.

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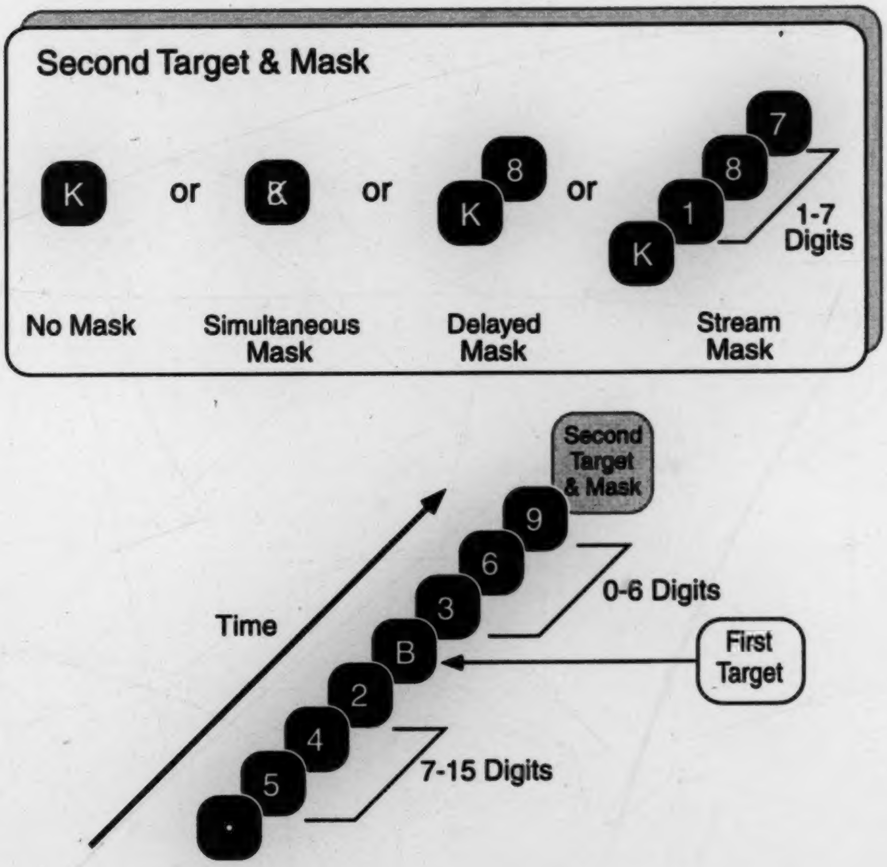
Second Target & Mask
K
or
or
8
K
or
7
8
1
K
1-7 Digits
No Mask
Simultaneous Mask
Delayed Mask
Stream Mask
Second Target & Mask
9
6
3
0-6 Digits
Time
B
First Target
2
4
5
7-15 Digits

Figure 1. Schematic representation of the display sequences in Experiment 1. All stimuli were presented sequentially in the centre of the screen. The first target was always masked by the next item in the sequence. The second target was masked in one of four ways: It was either the last item in the stream (No mask), or it was presented simultaneously with a digit (Simultaneous mask), or it was followed by a single digit (Delayed mask), or it was followed by between 1 and 7 digits (Stream mask).

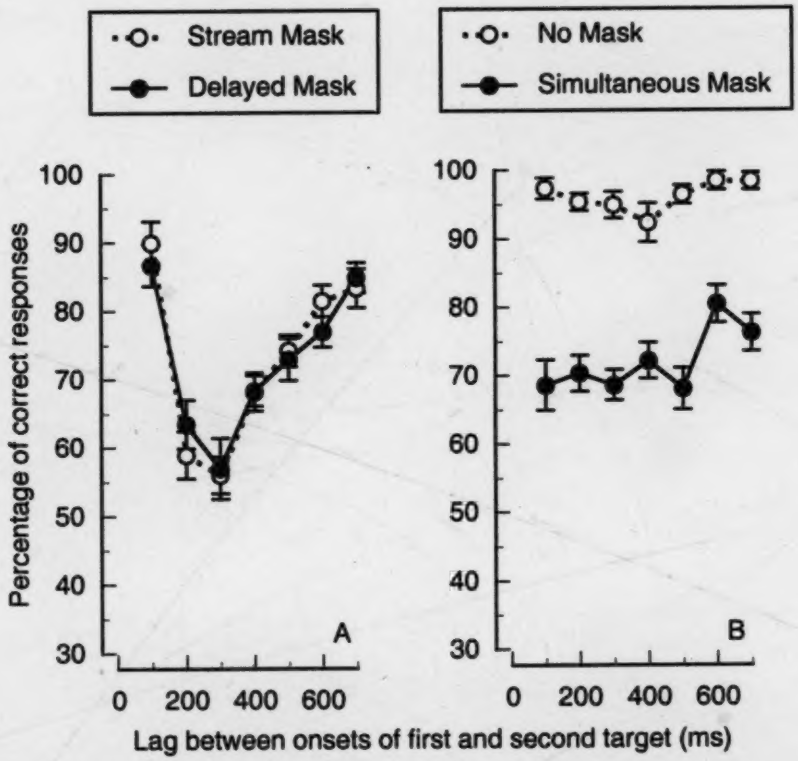

Figure 2. Results of Experiment 1. Mean percentages of correct identifications of the second target, given accurate identification of the first target. Illustrated in Panel A are the results of the Stream mask and Delayed mask conditions. Illustrated in Panel B are the results of the No mask and Simultaneous mask conditions. Error bars in this and subsequent figures represent one standard error and are appropriate for within-subjects pairwise comparisons (Loftus & Masson, 1994).

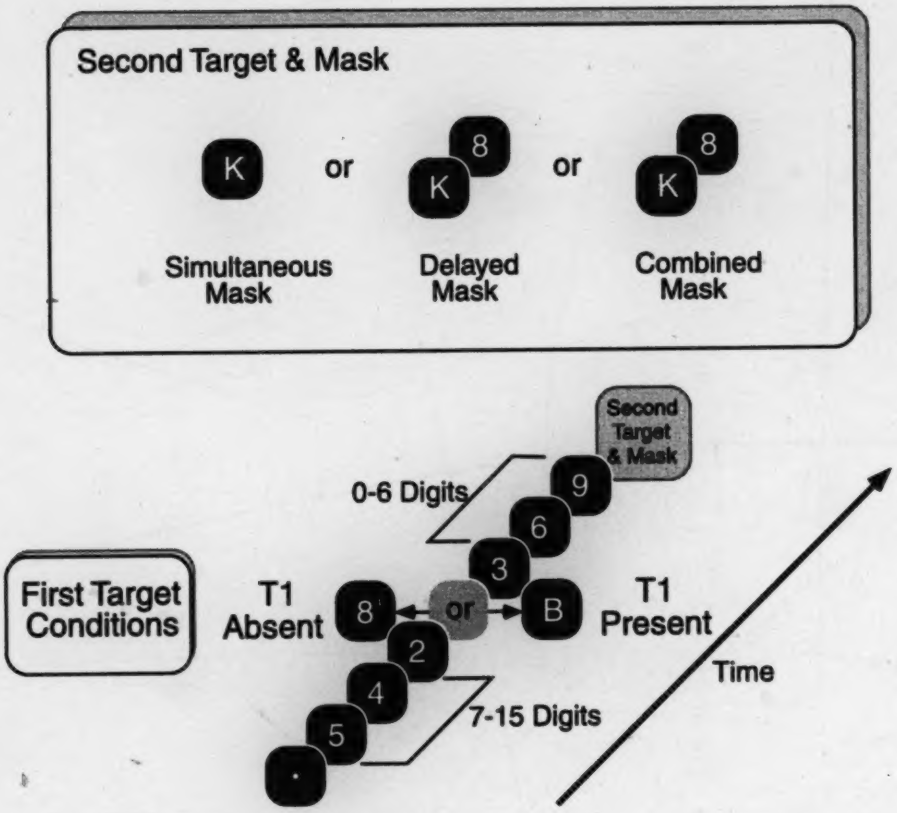
Second Target & Mask
K
or
8
K
or
8
K
Simultaneous Mask
Delayed Mask
Combined Mask
Second Target & Mask
0-6 Digits
9
6
3
First Target Conditions
T1 Absent
8
or
B
T1 Present
2
4
5
7-15 Digits
Time

Figure 3. Schematic representation of the display sequences in Experiment 2. All stimuli were presented sequentially in the centre of the screen. The first target was either Present or Absent, in which case the target letter was replaced with a digit. The second target was masked in one of three ways: It was either presented simultaneously with a 100 dot-mask (Simultaneous Mask), or it was followed by a single digit (Delayed Mask), or it was presented simultaneously with the dot-mask and was then followed by a digit (Combined Mask).

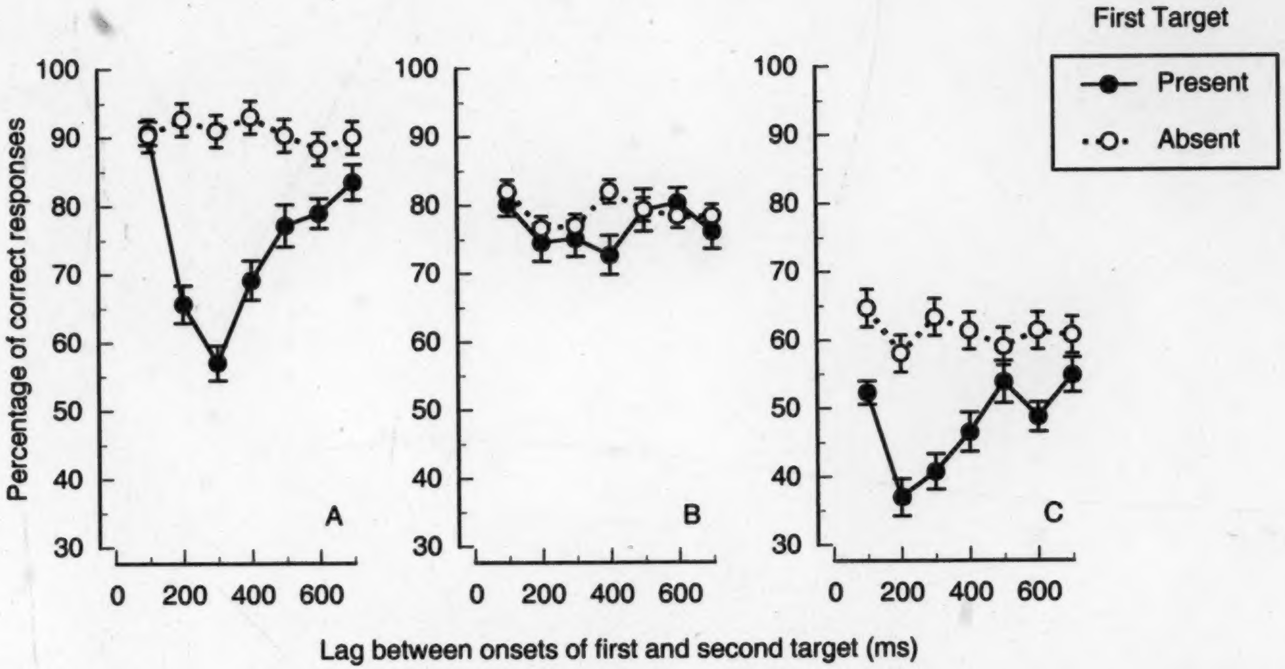

Figure 4. Results of Experiment 2. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct response. Notional lags for the Absent condition were devised based on the way in which the RSVP streams were constructed (see text). Shown in Panels A, B, and C are the results of the Delayed mask, Simultaneous mask, and Combined mask conditions respectively.

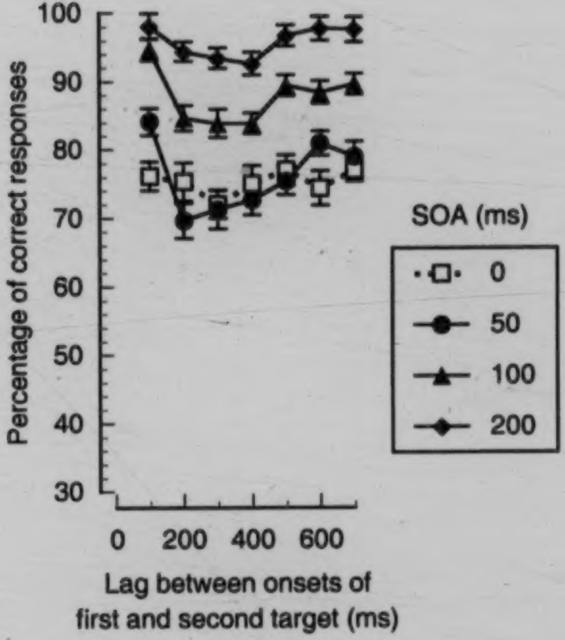

Figure 5. Results of Experiment 3. Mean percentages of correct identifications of the second target, given accurate identification of the first target. Stimulus-onset asynchrony (SOA) refers to the temporal interval that elapsed from the onset of the second target to the onset of the mask.

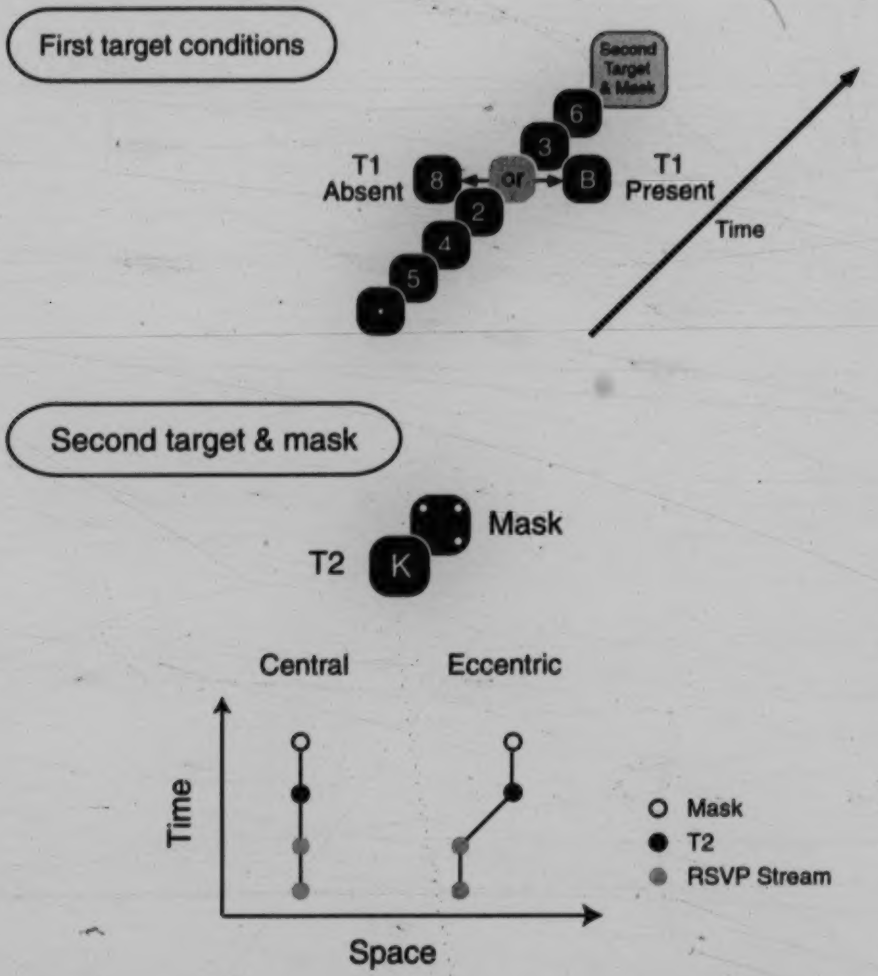
First target conditions
Second Target & Mask
6
3
T1 Absent
8
or
B
T1 Present
2
4
5
Time
Second target & mask
Mask
T2
K
Central
Eccentric
Time
Space
Mask
T2
RSVP Stream

Figure 6. Schematic representation of the display sequences in Experiment 4. All stimuli were presented sequentially in the centre of the screen. The first target was either Present or Absent, in which case the target letter was replaced with a digit. The second target was always masked by 4 dots that surrounded, but did not overlap the target. The second target and the mask were presented either in the same location as the rest of the stream (Central) or was presented above, below, to the left, or to the right of the stream (Eccentric).

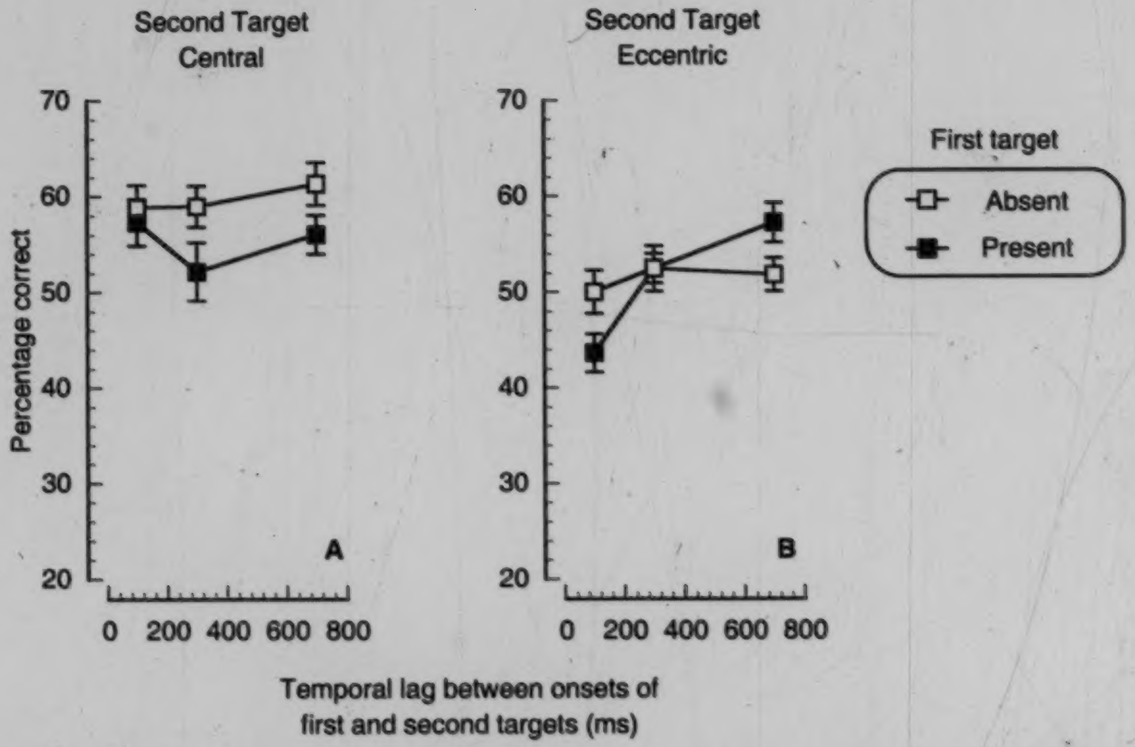

Figure 7. Results of Experiment 4. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses. Notional lags for the Absent condition in this and subsequent experiments were devised based on the way in which the RSVP streams were constructed (see text). Shown in Panels A and B are the results of the second target Central and Eccentric conditions respectively.

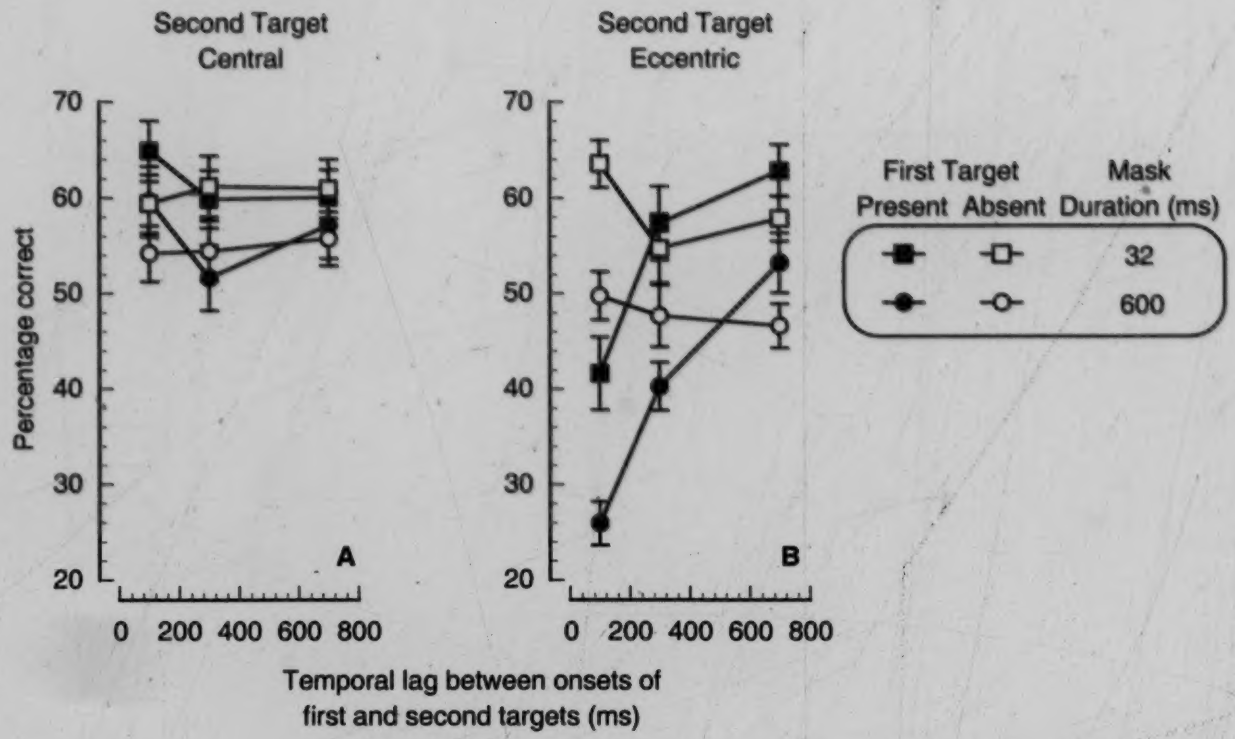

Figure 8. Results of Experiment 5. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses. Shown in Panels A and B are the results of the second target Central and Eccentric conditions respectively.

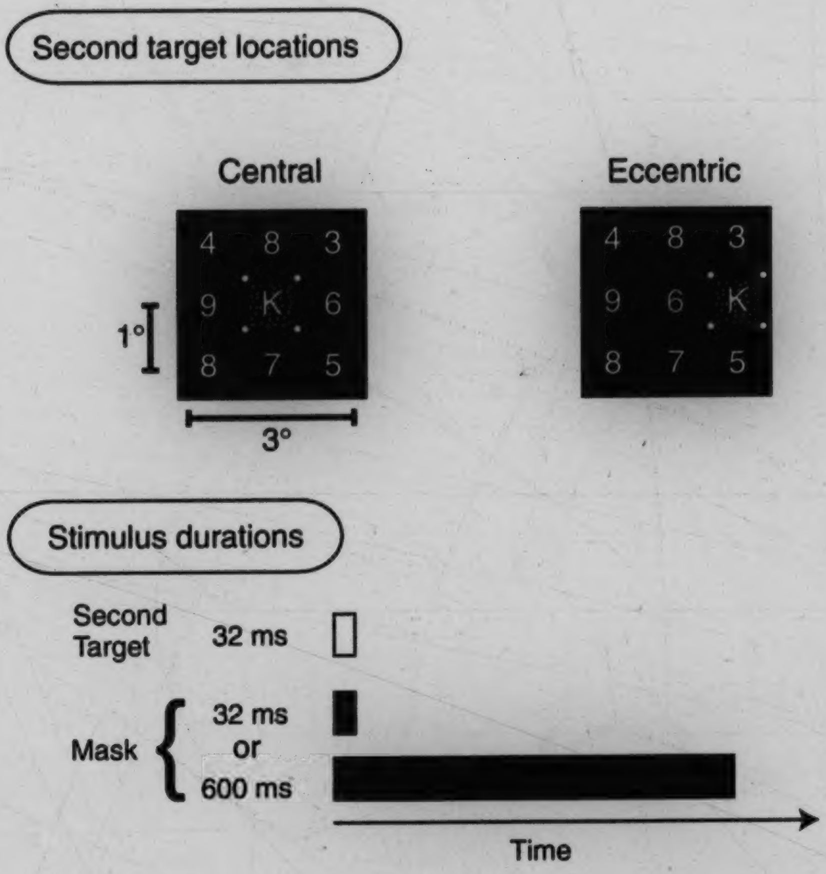
Second target locations
Central
Eccentric
4 8 3
9 K 6
8 7 5
4 8 3
9 6 K
8 7 5
1°
3°
Stimulus durations
Second Target
32 ms
Mask
32 ms
or
600 ms
Time

Figure 9. Schematic representation of the second target displays in Experiment 6. The displays consisted of a 3 x 3 matrix of stimuli (8 digits and 1 letter, i.e., the second target). Shown in the upper portion are the second target location conditions. The second target and the mask were presented either in the same location as the rest of the stream (Central) or were presented above, below, to the left, or to the right of the stream (Eccentric). Shown in the lower panel is the temporal profile of the second target and mask. The second target and mask were always presented simultaneously. The second target was always 32 ms and the mask was either 32 ms or 600 ms.

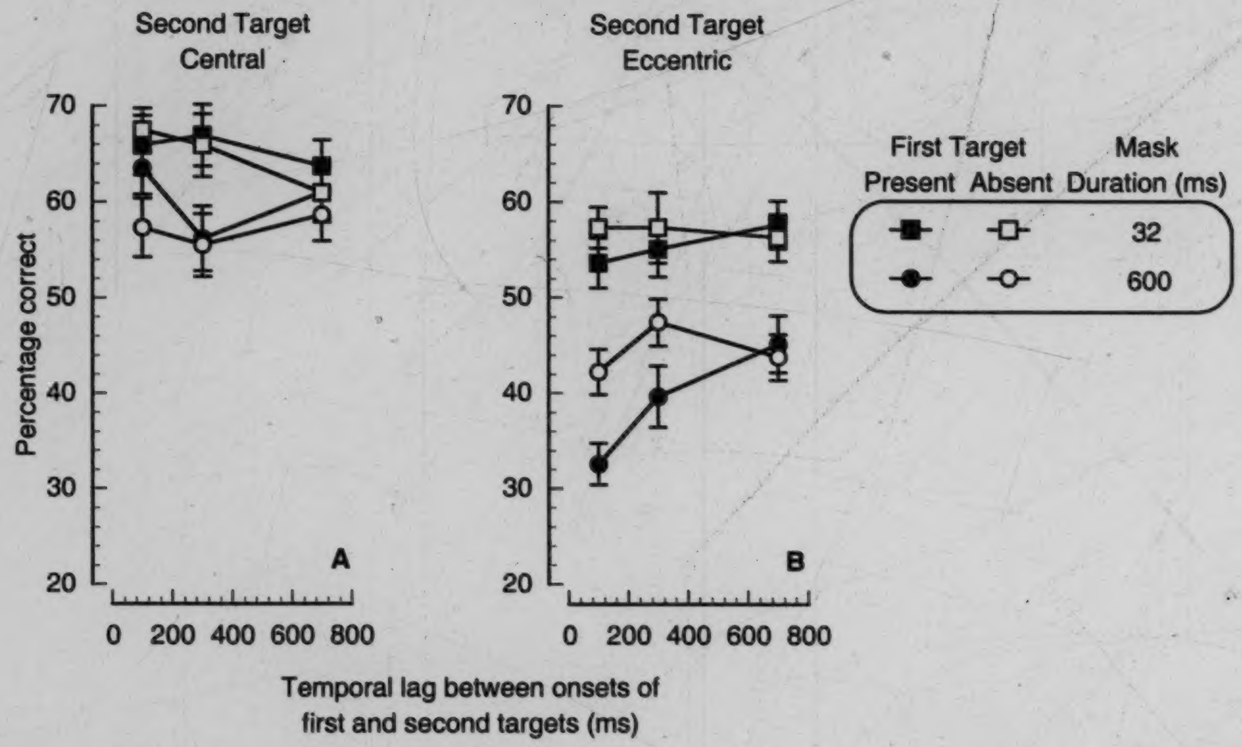

Figure 10. Results of Experiment 6. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses. Shown in Panels A and B are the results of the second target Central and Eccentric conditions respectively.

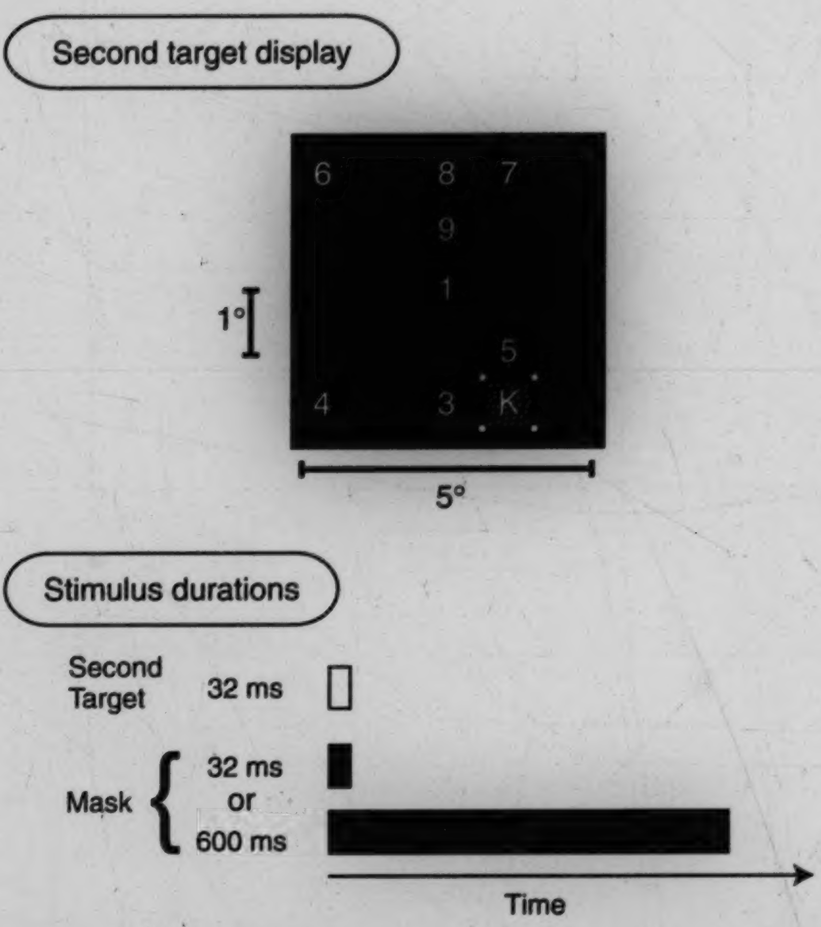
Second target display
6
8
7
9
1
1°
5
4
3
K
5°
Stimulus durations
Second Target
32 ms
Mask
32 ms
or
600 ms
Time

Figure 11. Schematic representation of the second target displays in Experiment 7. The displays consisted of a 5 x 5 matrix of stimuli (8 digits and 1 letter, i.e., the second target). Shown in the upper portion are the second target location conditions. The second target and the mask were presented together in random locations in the matrix, including fixation. The locations of the digits were also determined randomly with the constraint that a digit could not be shown in the same location as the target. Shown in the lower panel are the temporal profiles of the second target and mask. The second target and mask were always presented simultaneously. The second target was always 32 ms and the mask was either 32 ms or 600 ms.

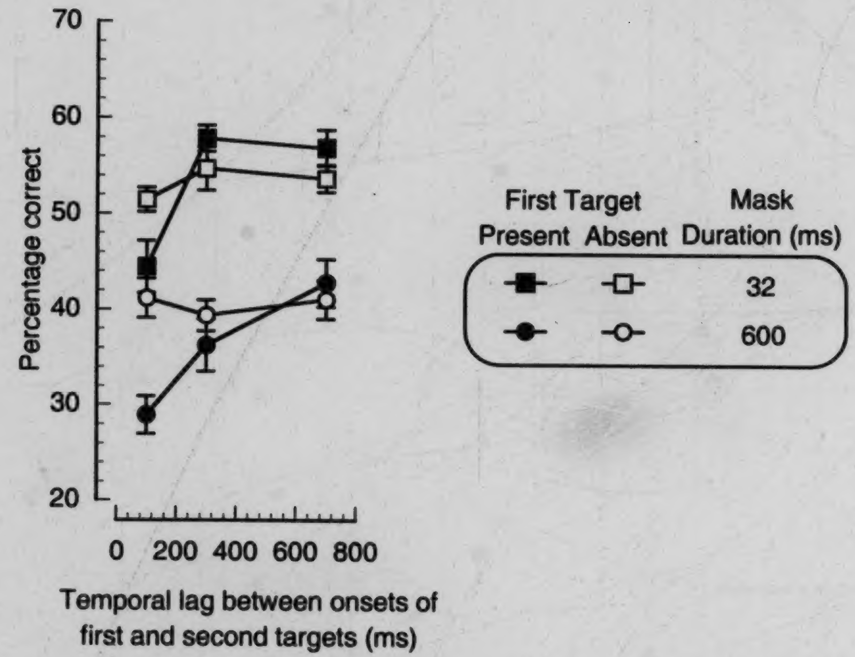

Figure 12. Results of Experiment 7. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses.

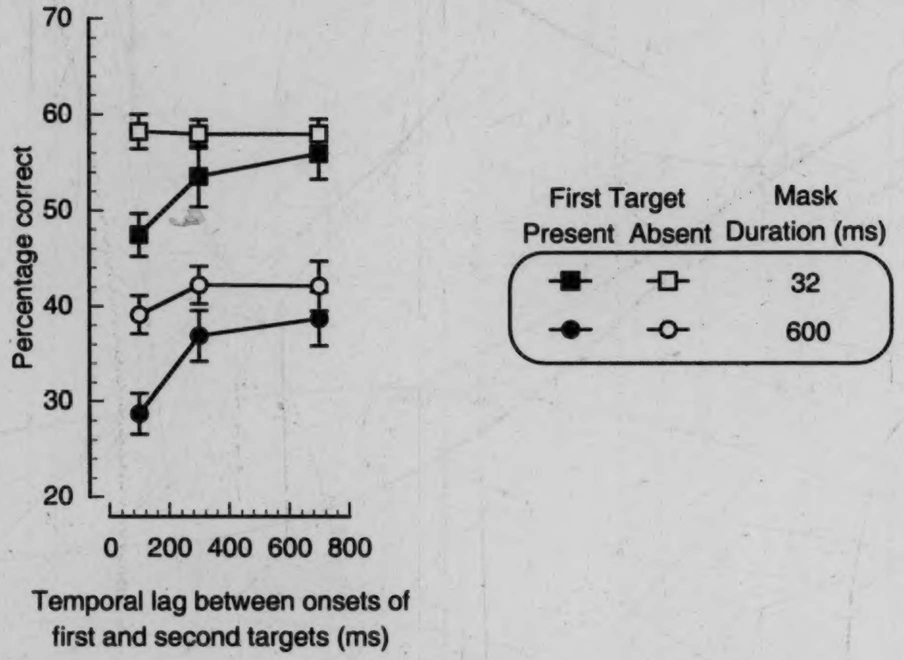

Figure 13. Results of Experiment 8. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses.

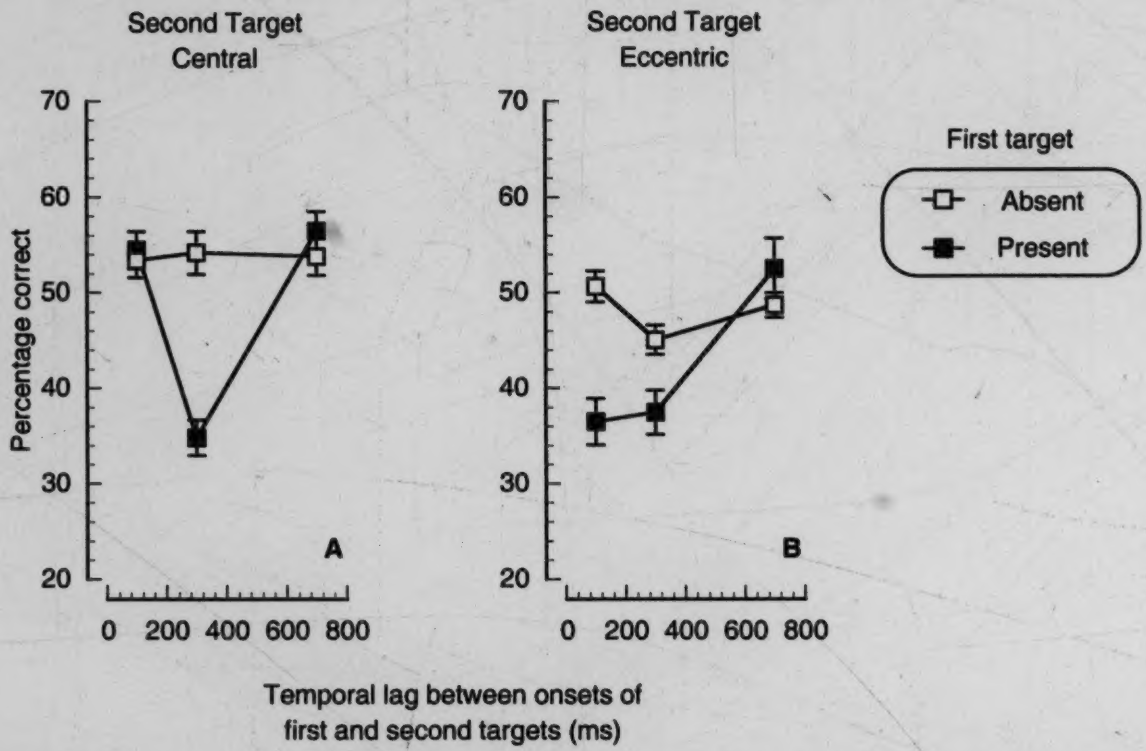

Figure 14. Results of Experiment 9. Scores in the Present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the Absent conditions are mean percentages of correct responses. Shown in Panels A and B are the results of the second target Central and Eccentric conditions respectively.

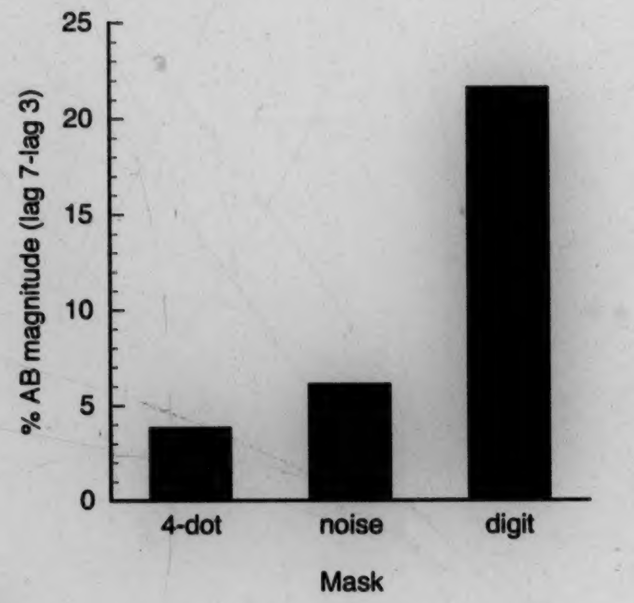

Figure 15. Results of AB magnitude analysis for three different types of backward masks: 4-dot (Experiment 4), noise (Experiment 3), and digit (Experiment 9). For each mask type, AB magnitude was calculated by subtracting the mean percentage of correct responses (collapsed across all subjects in the respective experiment) at lag 3 from the mean score at lag 7.